Chapter 6: Hector’s and Māui dolphin - Technical Summary

Hector’s and Māui dolphins are found only in New Zealand

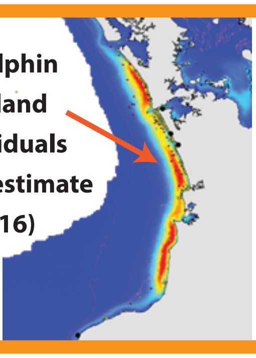
Both at risk from multiple threats, including fishing and disease

1. THE ISSUE IN BRIEF

- Hector’s and Māui dolphin (*Cephalorhyncus hectori*), comprising the South Island subspecies referred to as Hector’s dolphin (*C. h. hectori*) and the North Island subspecies known as Māui dolphin (*C. h. maui*), are endemic to the coastal waters of New Zealand.
- Hector’s and Māui dolphin are nationally vulnerable and critical (DOC 2019), respectively, and protected under the Marine Mammals Protection Act 1978 and the Fisheries Act 1996. Threats are managed through a Threat Management Plan
- Hector’s and Māui dolphins can drown when entangled in fishing gear, and new research has identified other potential threats to their conservation, including diseases (see e.g, box 3)

2. DISTRIBUTION AND ABUNDANCE

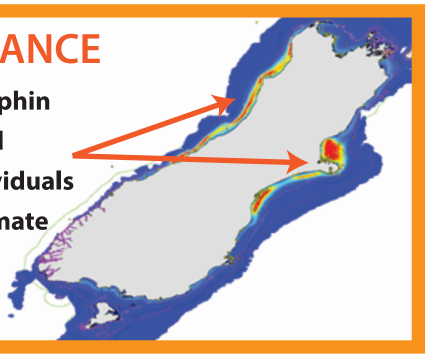
Māui dolphin
North Island
63 individuals
(model estimate 2015-2016)



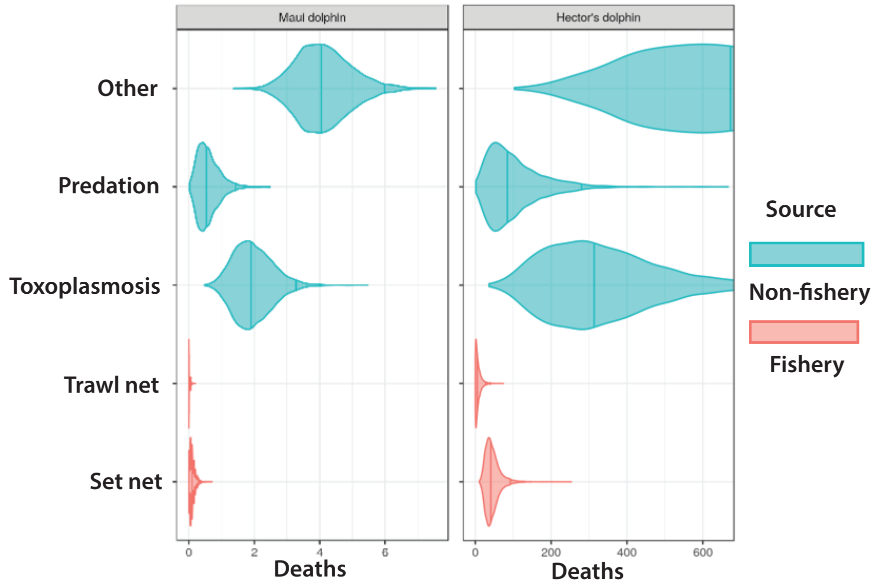
Dolphin abundance is estimated from aerial surveys and genetic census

Dolphin distribution is estimated using spatial habitat models fitted to survey data

Hector’s dolphin
South Island
14,594 individuals
(model estimate 2016)



3. MAIN THREATS



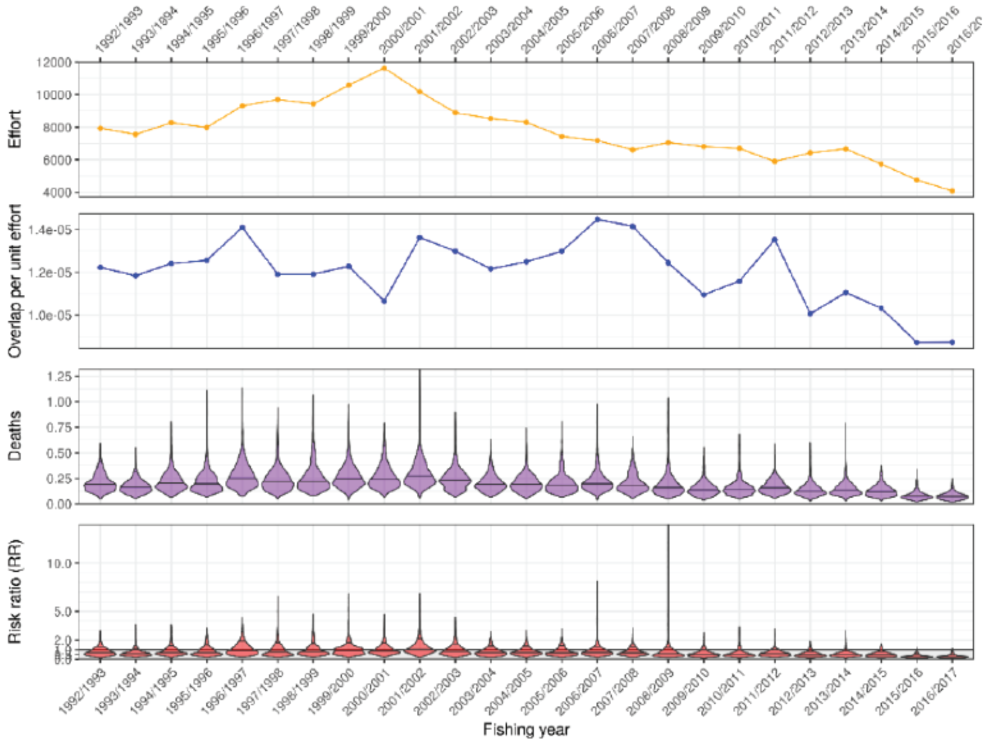
- A spatially explicit risk assessment is used to estimate the risk from different threats (see Chapter 3)
- Some risk of death comes from fishing interactions (commercial set nets and, to a lesser extent, commercial trawl nets)
- Experts estimate that mining and oil exploration activities may also affect Hector’s and Māui dolphin
- Toxoplasmosis, a parasitic infection spread to native wildlife by cats, has been recently highlighted as a major threat (see box 6)

Outputs of the multi-threat risk assessment model (Roberts et al. 2019). It is important to note that commercial fisheries deaths (set net and inshore trawl) are based on fisheries observer data and have been estimated with high certainty. Toxoplasmosis deaths have been estimated from necropsy results, which relies on the relative detectability of dolphin carcasses that have died from various causes, resulting in uncertainty that may not be reflected in the ranges above. All mortalities not accounted for in the remaining categories are in “other”

4. ONGOING MULTI-THREAT RISK ASSESSMENT

- Estimates different levels of risk to each subpopulation from multiple threats (including fishing, disease, etc.)
- Provides more accurate estimates than single-risk assessments
- Allows scientists to estimate when, where and how many e.g., fishing- or disease-related deaths occur
- Highlights e.g., the risk of Hector’s and Māui dolphin interactions with set nets or encounters with a disease

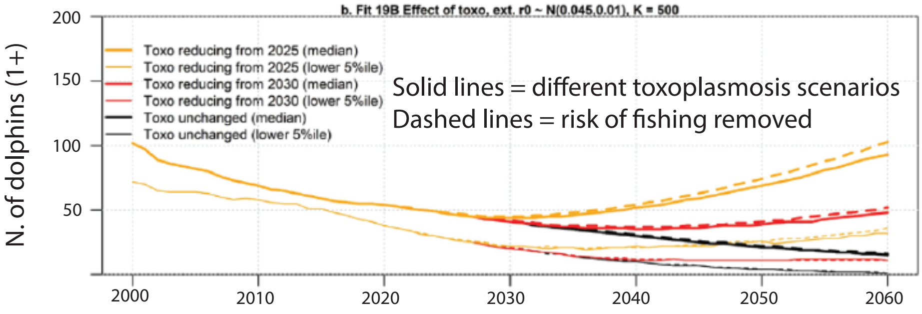
5. MAUI DOLPHIN AND FISHERIES INTERACTIONS



This figure shows historical decrease of set net fisheries effort (and its overlap with dolphins), leading to a corresponding decline in risk of death due to entanglement (Roberts et al. 2019)

- Fishing gear and area restrictions led to a reduction in fisheries interactions, and therefore fishing-related Māui dolphin deaths, since a peak in 2000-2001
- Additional restrictions to fishing have recently been announced to further reduce risk
- However, limiting fisheries risk alone may not be enough to halt the decline of Māui dolphins (see box 6)

6. TOXOPLASMOSIS



Solid lines = different toxoplasmosis scenarios
Dashed lines = risk of fishing removed

Maui dolphin population projections from an individual-based demographic model fitted to genetic mark-recapture data (Cooke et al. 2019). Solid lines represent projections of population numbers under different toxoplasmosis scenarios, dashed lines represent the effects of removing fisheries risks under each scenario

- The models demonstrate that risks from fishing and toxoplasmosis both need to be managed to allow Māui dolphins to recover

7. ONGOING RESEARCH

- Ongoing research is investigating the threat posed by toxoplasmosis, a disease to which some marine mammals may be particularly sensitive
- For these species to recover, other potential threats (e.g. other diseases or climate change) and novel technologies for population monitoring (aerial surveys through drones) are currently being assessed

6 HECTOR'S DOLPHIN (*CEPHALORHYNCHUS HECTORI HECTORI)* AND MĀUI DOLPHIN (*C. H. MAUI)*

Status of chapter	A substantial body of new science was undertaken in 2017–19 to inform the update of the Hector's and Māui dolphin Threat Management Plan. This chapter has been updated to include the key outcomes of this body of work.
Scope of chapter	This chapter briefly summarises: the biology, foraging ecology, population structure, abundance, and spatial distribution of Hector's and Māui dolphins (*Cephalorhynchus hectori hectori and C. h. maui*); fisheries and non-fisheries threats to Hector's and Māui dolphins; means of estimating fisheries impacts and subpopulation level risk; population demographic modelling; management of fisheries risk; and identified priority research questions, to guide future work.
Area	West coast North Island; all coastal areas of South Island.
Focal localities	Hector's and Māui dolphin habitat includes nearshore waters, mostly in locations with high water turbidity, around the full extent of the South Island and the west coast of the North Island. Hector's and Māui dolphins are also occasionally sighted around the north and east coasts of the North Island.
Key issues	The following issues are identified as key areas for further investigation: improved estimation of Hector's and Māui dolphin spatio-temporal density affecting spatial overlap with fisheries in low-dolphin-density locations, e.g., North Coast South Island (NCSI), South Coast South Island (SCSI),and Kaikōura; estimation of population status and trajectory at subpopulation scales; improved population size estimates for the North Coast South Island Hector's dolphin subpopulation; improved estimation of cryptic mortality in set nets; improved understanding of factors potentially affecting dolphin catchability in different types of fishing gears (for example low-headline-height trawl nets); options for fisheries mitigation.
Emerging issues	The following issues are identified as areas of emerging importance for future work: Improved carcass recovery and data capture from bycaught, beach-cast, and/or at-sea recovered carcasses to better understand non-fishery causes of death including from disease; improved understanding of the impact of toxoplasmosis on dolphin subpopulations; effects of other diseases such as brucellosis; improved understanding of potential biases arising from the use of beach-cast carcasses to understand threats; improved understanding of factors affecting reproductive success in different subpopulations (e.g., effects of fishing or climatic variability on dolphin prey and/or habitat); establishment of ongoing population monitoring for priority subpopulations; improved understanding of dolphin movements affecting connectivity between subpopulations.
Fisheries New Zealand research (current)	SEA2019-21 *Characterisation of DOC Hector's and Māui dolphin incidents data*; SEA2019-22 *Reanalysis of Banks Peninsula Hector's dolphin demographic data*; SEA2019-27 *Hector's dolphin trawl-deployed acoustics feasibility study*; PRO2019-11 *Historical reconstruction and characterisation of spatially explicit historical set net fishing;* PMM2018-07 *Updated spatially explicit fisheries risk assessment for New Zealand marine mammal populations*
NZ government research (current)	DOC Marine Conservation Services Programme (CSP): INT2017-03 *Identification of marine mammal, turtle and protected fish captured in New Zealand fisheries*; INT2018-03 *Improvement in observer photograph protocols and photograph curation*; INT2019-03 *Characterisation of marine mammal interactions*; POP2019-01 *Investigation of electronic device options to assess distribution, diving, and foraging behaviour of Hector's dolphins*; MIT2018-01 *Protected species engagement project*; MIT2019-01 *Dolphin dissuasive device mitigation in inshore fisheries*. Additional work being undertaken by DOC: Genetic sampling and necropsy (where suitable) of any retained Hector's and Māui dolphin carcasses; Validation of public sightings of Māui dolphins, and Hector's dolphins at the top of the South Island; Epigenetic aging of Hector's and Māui dolphins; Abundance estimate of Māui dolphins; Toxoplasmosis literature review; Toxoplasmosis research programme – currently being defined; Analysis of North Coast South Island Hector's genetic samples – not contracted at present. At DOC conservancy level there is a programme to evaluate acoustic data collected from C-pods.
Other research[1]	Otago University: Long-term study of Hector's dolphins at Banks Peninsula, including distribution, abundance, survival, reproduction, movement, and feeding ecology. Abundance and distribution of Hector's dolphins on Otago coast, Porpoise Bay. Effects of tourism and aquaculture. Auckland University: Population monitoring of Māui dolphins; genetics of Hector's and Māui dolphin subpopulations. Novel drone technologies for studying and monitoring dolphin populations (NGO partnership). Massey University: Necropsy of recovered Hector's and Māui dolphin carcasses; disease threats to dolphins.
Related chapters/issues	Chapter 3 (SEFRA); Chapters 4–5 (sea lions and fur seals); Chapter 7 (common dolphins)

---

[1] Du Fresne et al. (2012) compiled a bibliography of all Hector's and Māui dolphin research completed since 2003 (http://www.doc.govt.nz/documents/science-and-technical/drds332entire.pdf).

6.1 CONTEXT

Hector's and Māui dolphin[2] (*Cephalorhynchus hectori*), comprising the South Island subspecies referred to as Hector's dolphin (*C. h. hectori*) and the North Island subspecies known as Māui dolphin (*C. h. maui*), is endemic to the coastal waters of New Zealand. Like most other small cetaceans, the species is vulnerable to fishing-related mortality, particularly from set net fisheries (e.g., Read et al. 2006, Reeves et al. 2020, Geijer & Read 2013), in locations where fisheries and dolphins overlap.

Hector's and Māui dolphin was gazetted as a 'threatened species' by the Minister of Conservation in 1999 and is defined as a 'protected species' according to part 1, s2(1) of the Fisheries Act 1996 and s2(1) of the Marine Mammals Protection Act (MMPA) 1978. Management of fisheries impacts on Hector's and Māui dolphins is legislated under both these acts. The MMPA 1978 allows for the approval of a population management plan for any protected species, within which a maximum allowable level of fishing-related mortality may be imposed. For threatened species, this level 'should allow the species to achieve non-threatened status as soon as reasonably practicable, and in any event within a period not exceeding 20 years' (MMPA 1978, p.11). If a population management plan has been approved, the Fisheries Act 1996 requires that all reasonable steps be taken to ensure that the maximum allowable level of fishing-related mortality is not exceeded, and the Minister may take other measures necessary to further avoid, remedy, or mitigate any adverse effects of fishing on the relevant protected species. In the absence of a population management plan, 'the Minister may, after consultation with the Minister of Conservation, take such measures as he or she considers are necessary to avoid, remedy, or mitigate the effect of fishing-related mortality on any protected species, and such measures may include setting a limit on fishing-related mortality' (Fisheries Act 1996, p.66).

No population management plan has been produced for either Hector's or Māui dolphins, and no maximum allowable level of fishing-related mortality has been set. Human-induced threats to Hector's and Māui dolphins are instead managed through a Threat Management Plan (TMP); first developed jointly by the Department of Conservation (DOC) and the former Ministry of Fisheries (MFish) in 2007. The TMP is not a statutory document, but a management plan identifying human-induced threats to the populations and outlining strategies to mitigate those threats. The TMP is reviewed approximately every 5 years. A review of the Māui portion of the TMP undertaken in 2012 provided a comprehensive overview of information relating to the biology, distribution, threats to, and management of Māui dolphins (MPI & DOC 2012). This review was informed by a spatially explicit, semi-quantitative risk assessment conducted using an expert panel, applying an early modification of the SEFRA method (Chapter 3), to identify, analyse, and evaluate all threats to Māui dolphins (Currey et al. 2012).

A full review of the TMP was undertaken in 2019, including a comprehensive review of new science as well as a collaborative stakeholder engagement process to inform the policy aspects of the TMP, including articulation of a vision statement and population-level goals and objectives. Stakeholder workshops were attended by iwi and hapū, commercial and recreational fishing industry representatives, fishers, scientific experts, dolphin advocates and environmental NGOs, local government representatives, dolphin tourism business representatives, and interested members of the public. The review proposed a new vision statement to guide the TMP:

New Zealand's Hector's and Māui dolphin populations are resilient and thriving throughout their natural range.

To achieve this vision the review recommended adoption of a set of long- and medium-term goals. One of the goals is to:

Ensure known human-caused threats are managed within levels that allow subpopulations to thrive and recover.

To operationalise this goal within the definition of the Population Sustainability Threshold (PST; see Chapter 3), population outcomes were proposed for Māui dolphins and for each Hector's dolphin subpopulation, corresponding to a maximum impact that the subpopulation can sustain while still achieving the defined objective. The population outcomes thereby help to define specific measurable

---

[2] In this document, 'Hector's dolphin(s)' refers to the South Island subspecies (*Cephalorhynchus hectori hectori*), and 'Māui dolphin(s)' refers to the North Island subspecies (*C. hectori maui*). 'Hector's and Māui dolphin(s)' refers to both subspecies collectively (*C. hectori*). This approach is taken to avoid confusion and enable distinction between the South Island subspecies and the species as a whole.

metrics by which to reduce the impact of particular threats (e.g., fishing).

Stakeholders discussed the need for population outcomes to reflect the urgent conservation status of Māui dolphins in particular, and to consider the specific circumstances of small or reproductively isolated Hector's dolphin subpopulations. Note however that the choice of population outcome itself is a policy decision, reflecting a societal value judgment not a scientific assessment.

The following population outcomes were proposed:

- *Māui dolphins: Human impacts are managed to allow the population to increase to a level at or above 95 percent of the maximum number of dolphins the environment can support.*
- *Hector's dolphins: Human impacts are managed to allow each subpopulation to increase to a level at or above 90 percent of the maximum number of dolphins the environment can support.*

A population outcome of 95 percent for Māui dolphins (with high certainty, see footnote below) means that human-induced deaths need to be as near as practicable to zero.

The population of Hector's dolphins is much larger than the Māui dolphin population. Therefore, the level of impact that Hector's dolphin subpopulations can sustain will be higher while still allowing the population to achieve a defined population objective, expressed in terms of maintaining average population size at or above a very high proportion of the maximum number of dolphins the environment can sustain[3].

The 2019 review was informed by a more comprehensive spatially explicit risk assessment including fisheries and non-fishery threats to Hector's and Māui dolphins, and demographic population models for separate regional subpopulations (Roberts et al. 2019a). The risk assessment incorporated updated estimates of population size, demographic parameters affecting population growth and recovery potential (r^{max}), and improved estimates of the distribution of the dolphins to better estimate spatial overlap with threats, adapting methods described in Chapter 3. This information was used to reassess the risk of commercial fishing, recreational set net fishing, and non-fishing-related threats for the Hector's and Māui dolphin local and subpopulations, and to evaluate the effectiveness of current and new potential management measures and monitoring programmes to address those threats. As at June 2020, decisions on the revised Hector's and Māui dolphin Threat Management Plan are still pending.

6.2 BIOLOGY

6.2.1 TAXONOMY

Hector's and Māui dolphin (also recognised as the South and North Island Hector's dolphin) are designated as subspecies in acknowledgement of their common ancestral connections, but there are current differences in morphology and genetics as a result of the North Island dolphins being isolated from the South Island around the time of the last glacial period about 15 000 years ago (Pichler et al. 2001, Baker et al. 2002). Due to the similar appearance of both Hector's and Māui dolphins, genetic markers are the only way to identify which subspecies an individual belongs to. The species is classified within the *Cephalorhyncus* genus of dolphins, which includes three other species found in the Southern Hemisphere (Heaviside's dolphin found off South Africa and Namibia, the Chilean dolphin found in the coastal waterways of Chile, and the Commerson's dolphin found in Argentina, the Falkland Islands, and the Kerguelen Islands).

6.2.2 REPRODUCTIVE BIOLOGY

Information from incidentally captured or stranded Hector's dolphins indicates that Hector's and Māui dolphins reach sexual maturity around 5–9 years old. The dolphins appear to live until at least their mid-20s based on mark-recapture and necropsy data (Gormley 2009, Rayment et al. 2009b, Webster et al. 2009). These estimates are used in a Bayesian assessment integrating information from ageing and maturity data, and a novel invariant based on body

---

[3] Note that with respect to particular impacts (e.g., fisheries), where decision makers wish to ensure that a population objective is achieved with high certainty, this is achieved by comparing the upper 90th or 95th percentile of the impact estimate against the PST, rather than by adjusting the definition of the PST itself. For example, in advice to inform the update of the dolphin TMP, evaluation against the fisheries impact objective used the 95th percentile estimate of fisheries impact.

length at maturity relative to asymptotic length, which indicated that the age at which 50% of animals are mature is 6.91 y (95% credible interval = 5.82–8.24) (Edwards et al. 2018).

Breeding occurs in summer, during which larger aggregations of dolphins engage in high levels of activity associated with their multi-mate breeding system (Slooten et al. 1993). There is competition amongst males to mate with the few females in oestrus, and males move between different groups of dolphins to increase their mating opportunities (Slooten 1991, Slooten et al. 1993). Females give birth to a single calf during the summer and will come into oestrus again about2 years later at around the time the previous calf is weaned (Dawson 2019). Calves are born large relative to the mother (neonatal length 60–75 cm; Slooten & Dawson 1994). Calves grow rapidly in the first few years and reach adult size at around five years old (Webster et al. 2010).

Hector's and Māui dolphins are typically found in small groups of 1–14 individuals (Slooten et al. 2006, Rayment et al. 2010, 2011b, Oremus et al. 2012). Mean group sizes appear to be larger when estimated from boat-based surveys (e.g., Webster et al. 2009, Oremus et al. 2012) compared with aerial surveys (e.g., Slooten et al. 2006, Rayment et al. 2010) possibly due to the species' boat-positive behaviour (e.g., Dawson et al. 2004). Webster et al. (2009) found that Hector's dolphin groups were highly segregated by sex, with 91% of groups of up to five individuals being all male or all female; similar patterns of sex segregation are not apparent in Māui dolphins (Oremus et al. 2012). Although often associated with mother-calf pairs outside the breeding season, males play no role in calf rearing, but females often form nursery groups, comprising either a single mother-calf pair or small aggregations of mother-calf pairs (Bräger 1999, Webster et al. 2009, Oremus et al. 2012).

6.2.3 FORAGING ECOLOGY

Miller (2014) and Miller et al. (2013) investigated the diet and feeding ecology of Hector's and Māui dolphins through the examination of diagnostic prey remains in the stomachs of 63 incidentally captured and beach-cast animals and stable isotope analyses. They concluded that Hector's dolphins take a wide variety of prey throughout the water column (in total 29 taxa were recorded), but that the diet is dominated by a few midwater and demersal species. The diets of Hector's dolphins from the South Island west and east coasts were significantly different, due largely to the high prevalence of javelin fish (*Lepidorhynchus denticulatus*) on the west coast, and a greater prevalence of demersal prey species on the east coast (Miller et al. 2013). Nonetheless red cod (*Pseudophycis bachus*) was the most abundant prey species by mass on both coasts. Red cod comprised 37% of the total dietary mass and may be particularly important to east coast South Island (ECSI) females (60% of the dietary mass of 19 individuals). Five other taxa — arrow squid (*Nototodarus* sp.), ahuru (*Auchenoceros punctatus*), sprat (*Sprattus* sp.), sole (*Peltorhamphus* sp.), and stargazer (*Crapatulus* sp.) — together comprised 30% of the total dietary mass from all 63 stomachs. Prey items ranged from an estimated 0.5–60.8 cm in length, but the majority were less than 10 cm in length, indicating that for the larger fish species, predation focuses on juveniles. Weir (2018) reconstructed the mean lengths of the main prey species compiled by Miller et al. (2013) as follows: red cod: 17.9±10.1 cm; arrow squid 17.1±9.4 cm; sprat 10.4±2.1 cm; stargazer 10.2±4.1 cm; ahuru 8.3±3.3 cm; and sole 4.4±4.0 cm.

Only two samples were derived from Hector's and Māui dolphins off the west coast North Island (WCNI), containing red cod, ahuru, sole, and flounder (*Rhomboselea* sp.; Miller et al. 2013).

The stomachs of the six smallest dolphins in the total sample (standard length under 90 cm) contained only milk; a single specimen (at 99 cm long) contained milk and remains of arrow squid in the stomach; but specimens longer than 107 cm did not contain milk (Miller et al. 2013).

Although demersal fish account for the majority of dolphin diet by number and by mass, Hector's dolphins are also occasionally seen foraging near the sea surface on small fish including sprat, pilchard (*Sardinops neopilchardus*), and yellow-eyed mullet (*Aldrichetta forsteri*; Miller et al. 2013), sometimes in association with white-fronted terns (*Sterna striata*; Bräger 1998).

Hector's dolphins have been observed foraging in association with demersal trawlers at Banks Peninsula, presumably targeting the fish disturbed but not captured by the trawl net (Rayment & Webster 2009). New work is underway under Fisheries New Zealand project SEA2019-27 to investigate options using vessel-deployed hydrophone arrays to better characterise Hector's dolphin interactions with trawl fishing operations.

6.2.4 DISTRIBUTION AND MOVEMENT

Historically, Hector's dolphins were distributed throughout the coastal waters around most of the South Island and around large parts of the North Island. There are several different Māori names for these dolphins depending on the iwi or hapū in the region they were observed, with the dolphins regularly appearing in local narratives around New Zealand. This reflects the common presence of these dolphins throughout coastal waters in pre-European times (McGrath submitted).

Hector's dolphins occur in highest densities off the west coast of the South Island (WCSI) between Jackson Bay and Kahurangi Point (Bräger & Schneider 1998, Rayment et al. 2011a), off the east coast (ECSI) between the Marlborough Sounds and Otago Peninsula (Dawson et al. 2004, MacKenzie & Clement 2014) and off the south coast (SCSI) between Toetoes Bay and Porpoise Bay and in Te Waewae Bay (Bejder & Dawson 2001, Dawson et al. 2004). Population densities are lower in the intervening stretches of coast, e.g., Fiordland (Bräger & Schneider 1998), in Golden Bay (Slooten et al. 2001) and along the south Otago coast (Jim Fyfe pers. comm.), suggesting a spatially discontinuous distribution.

There are clear genetic differences between Hector's dolphins in different locations, including over relatively small distances (Pichler et al. 1998, Pichler and Baker 2000, Hamner et al. 2012a, Hamner et al. 2016, 2017). Genetic differentiation at this scale is unusual among cetaceans in the absence of geographical barriers and reflects that individual Hector's dolphins are thought to have small home ranges and high philopatry (Pichler et al. 1998, Bräger et al. 2002, Rayment et al. 2009b). Genetic analysis of Hector's dolphins from the North Coast South Island (NCSI) and from Kaikōura highlight the importance of understanding connectivity between smaller local populations and larger neighbouring subpopulations (Hamner et al. 2016, Baker et al. 2017).

Bräger & Bräger (2018) found that home range sizes are likely to be population-specific and contingent on local topographic and other environmental features. For example, the deep-sea Kaikōura Canyon may constitute a substantial dispersal barrier; evidence suggests that dolphins tend not to cross the canyon, as reflected in genetic differences between dolphins north and south of the canyon (Weir and Sagnol 2015, Hamner et al. 2016, Bräger and Bräger 2018. The ECSI populations off Kaikōura and Moeraki compared with WCSI populations off Westport-Greymouth and Jackson Bay also showed significant differences in individual movement patterns, based on photo-ID observations (Bräger & Bräger 2018). Satellite tagging of three Hector's dolphins near Banks Peninsula in 2004 recorded maximum movements of 50.9 to 66.5 km over deployments lasting from four to seven months (Stone et al. 2005). Rayment et al. (2009a), using photo-ID records of 53 dolphins near Banks Peninsula, recorded maximum distances between sightings of each dolphin ranging from 9.3 km to 107.4 km for the period 1985–2006. Rare observations of Hector's dolphin movements over 400 km (Hamner et al. 2014a) are considered to be exceptional behaviour.

Genetic testing of WCNI dolphins since 2001 has identified a small number of Hector's dolphins located within the contemporary distribution of Māui dolphin as far north as the Manukau Harbour. These results confirm the occurrence of at least occasional long distance dispersal by Hector's dolphins (Hamner et al. 2012b, Baker et al. 2016b). Although some of these dolphins were observed in association with Māui dolphins, to date there is no evidence of successful interbreeding (Hamner et al. 2014b).

Presumed Māui dolphins sightings extend from Maunganui Bluff to New Plymouth (Slooten et al. 2005, Du Fresne 2010, Hamner et al. 2012a, 2012b; DOC 2020b). Research surveys since 2003 are focused in areas of highest dolphin density between Kaipara Harbour and Kawhia (Slooten et al. 2005, Du Fresne 2010, Hamner et al. 2012a, 2012b).

Historical samples from strandings and museum specimens have allowed genetic identification of Māui dolphins off the WCNI from Dargaville to Wellington (DOC 2020a, Pichler 2002). Pichler & Baker (2000) reported genetic analysis of samples of Hector's and Māui dolphins dating back to 1870 and suggest that abundance has declined and geographic range has contracted over the past 140 years. Historical strandings data also indicate that the geographical range of Māui dolphins contracted from the 1970s to the 1990s (Russell 1999), but most of these dolphins were not genetically identified and so could also have included Hector's dolphins.

There are occasional reported public sightings of Hector's and/or Māui dolphins from all around the North Island, including validated sightings (e.g., Baker 1978, Cawthorn 1988, Russell 1999, Freeman 2003, McGrath submitted). The Department of Conservation maintains a website encouraging the public to report sightings (DOC 2020b) and uses a systematic validation process whereby scientific experts contact each person reporting a sighting in the North Island[4]. The locations of both validated and un-validated sightings are shown in Figure 6.1. That even un-validated sightings tend to cluster in locations where spatial distribution models predict that the habitat is most suitable (see below) further supports their credibility. It is typically assumed that North Island sightings in locations outside the known core Māui dolphin area are indicative of transient animals from other locations rather than resident local populations; i.e., as at June 2020 there are no confirmed records of newborn calves in North Island locations outside the known Māui dolphin subpopulation area. However there remains the possibility that Māui or Hector’s dolphins may expand their current distribution or disperse to recolonise suitable North Island habitats in future, e.g., in Hawke Bay or the South Taranaki Bight near Whanganui.

6.2.5 HABITAT PREFERENCE AND SPATIAL ABUNDANCE PATTERNS

Hector’s and Māui dolphins typically inhabit shallow waters close to shore, including in harbours and bays and in open coastal waters (e.g., Rayment et al. 2009a, Rodda and Moore 2013, Derville et al. 2016, Bräger & Bräger 2018). There are differences in daily and seasonal distribution patterns in different locations (e.g., Dawson & Slooten 1988, Stone et al. 1995, Bräger et al. 2003, Rayment et al. 2009b, Turek et al. 2013, MacKenzie & Clement 2014, 2016). Near Banks Peninsula, Hector’s dolphins are sighted most frequently close to shore, but have also been observed up to 22 nm offshore, especially in Pegasus Bay over shelf waters shallower than 50 m depth (Bräger et al. 2003; see Figure 6.5). In contrast, the WCSI Hector’s dolphins generally have longer alongshore ranges, but are usually found within approximately 6 nm of shore (Bräger et al. 2003, Rayment et al. 2011a, MacKenzie & Clement 2016, Bräger & Bräger 2018). Similar to the ECSI, highest density areas are mostly within the 50 m depth contour (Figure 6.5).

Māui dolphins are most abundant in inshore waters between Manukau Harbour and Port Waikato. Most sightings are concentrated within 4 nm of the coast (Slooten et al. 2005, MPI & DOC 2012, Oremus et al. 2012); with lower numbers of sightings out to 7 nm (Du Fresne 2010, Thompson & Richard 2012) and very occasional sightings further offshore (Figure 6.5). Passive acoustic monitoring using deployed hydrophones revealed a similar pattern at the core of the Māui dolphin range near Manukau Harbour, with the majority of detections occurring within 4 nm, but occasional detections further offshore to a maximum distance of 10 nm (Nelson & Radford 2018).

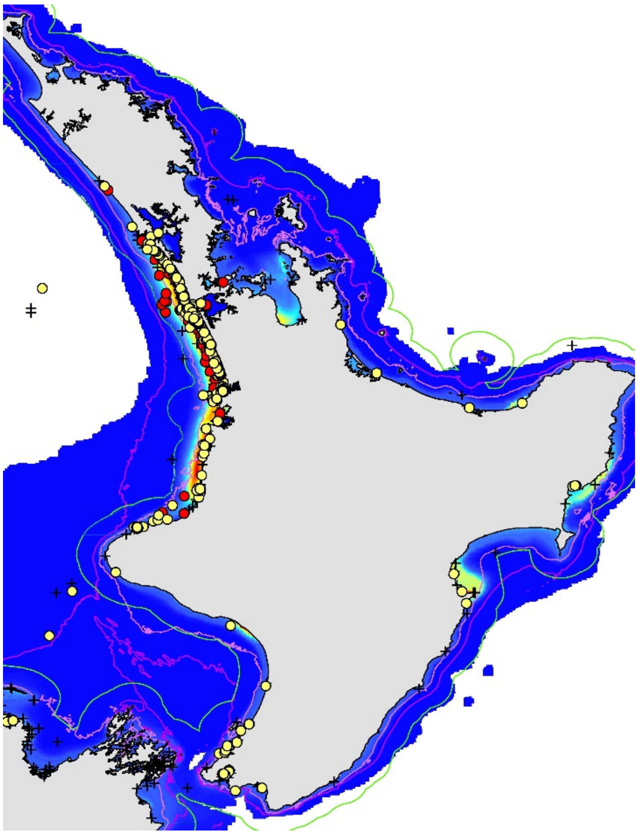


Figure 6.1: Locations of all reported public sightings of Hector’s or Māui dolphins around the North Island. Yellow = validated summer sighting; Red = validated winter sighting. Black cross = un-validated sighting. Sightings locations are superimposed on outputs of a spatial habitat suitability model, in which predictions were based on water turbidity and the estimated prevalence of dolphin prey (from Roberts et al. 2019a; see section 6.2.9).

Historically, Māui dolphins have been sighted in three North Island harbours: Kaipara, Manukau, and Raglan (Slooten et al. 2005; Scali 2006); but harbour sightings are rare in recent decades (Rayment et al. 2011b, Derville et al.

---

[4] The DOC sightings confirmation process is described here: https://www.doc.govt.nz/globalassets/documents/conservation/native-animals/marine-mammals/mauis-validation-system.pdf

2016). Passive acoustic monitoring via deployed hydrophones in these three harbours, in addition to Kawhia Harbour, revealed very occasional dolphin presence inside harbours near the harbour mouths (Rayment et al. 2011b, Wright & Treganza 2019). Distribution models fitted to public sightings data also predict very low densities inside harbours (Roberts et al. 2019a) as shown in Figure 6.3.

Numerous studies have reported an affinity for high-turbidity water and avoidance of clear water by Hector's and Māui dolphins (e.g., Abel 1971, Baker 1972, Baker 1978, Bräger & Bräger 2018, Bräger et al. 2003, Derville et al. 2016, Ferreira & Roberts 2003, Rayment et al. 2009a, Russell 1999, Rodda & Moore 2013, Weir and Sagnol 2015, Derville et al. 2016, Bräger & Bräger 2018; McGrath submitted). These observations are reflected in the outputs of quantitative habitat preference models fitted to boat-based sightings (e.g., Bräger et al. 2003, Derville et al. 2016, Miller 2015) and aerial survey sightings, as described by Roberts et al. (2019a). The dolphins' preference for turbid waters is also reported from direct behavioural observations in which dolphins following boats were typically observed to stop and turn back at the boundary between turbid and clear waters, without reference to depth or distance from shore (Russell 1999).

Dolphin distributions appear to shift further offshore during the winter, most likely associated with seasonal changes in the spatial extent of preferred turbid-water conditions and seasonal shifts in the distribution of their preferred prey (Miller 2015; Roberts et al. 2019a). Rayment et al. (2010) conducted aerial surveys of Hector's dolphins at Banks Peninsula from the coast to 15 nm offshore over three summers and winters. A significantly larger proportion of the population was sighted inside the 4 nm set net restriction zone in summer (mean = 81%; s.e. = 3.60) than in winter (mean = 44%; s.e. = 3.60). Similar seasonal differences in distribution were observed during the ECSI aerial surveys (MacKenzie & Clement 2014; Figure 6.2): in the Banks Peninsula (BP) stratum, 45% of the local population was observed inside the 4 nm set net exclusion zone in summer, compared with only 26% for the winter population. Similarly, in the Clifford Bay and Cloudy Bay (CCB) stratum, 47% of the local summer population and 14% of the local winter population were within the 4 nm set net fisheries exclusion zone (Miller 2015, Miller et al. 2013, MacKenzie & Clement 2014, Brough et al. 2019). Similar seasonal offshore movements were reported by Du Fresne & Mattlin (2009) and MacKenzie & Clement (2014).

These observations, including seasonal inshore-offshore movement patterns, are largely consistent with the predictions of Māui and Hector's dolphin spatial distribution models reflecting habitat preference functions fitted to Hector's dolphin aerial survey observations (Roberts et al. 2019a), reproduced below in Figure 6.5. That spatial predictions in the North Island are largely consistent with independent observations (i.e., public sightings), despite the preference functions having been parameterised using aerial survey data in the South Island, lends strength to the proposition that they reflect actual behavioural or habitat drivers of distribution, rather than incidental correlations. More systematic forms of model validation could include withholding a spatially contiguous portion of the data and using the remainder of the data to predict into areas in which data were withheld (e.g., using ECSI data to predict distributions on the WCSI, and vice versa).

6.2.6 POPULATION SIZE

The population sizes of the different Hector's and Māui dolphin subpopulations have been estimated by formal surveys since the mid-1980s. Different survey methods were used through time, including: boat-based surveys (1985–2000), aerial surveys (since 2000) (section 6.2.6.2) and genetic mark recapture (since 2001) (section 6.2.6.1). Population estimates are summarised in Table 6.1. Aerial surveys (which are less sensitive to swell height) consistently produce higher population size estimates for this species compared with boat-based surveys in similar areas (MacKenzie & Clement 2014, Slooten et al. 2004). For example, the ECSI aerial survey in 2013 estimated 2–2.5 times as many dolphins within 4 nm of the coast comparedwith boat-based surveys in 1997–2000 (Dawson et al. 2004, MacKenzie & Clement 2014). Also note that the wide uncertainty around survey-based population size estimates (CV typically around 20%) hampers our ability to detect population changes, unless that change is very large (section 6.2.7). The most recent comprehensive abundance estimates for Hector's dolphins are from aerial surveys of the coastal waters (excluding harbours and enclosed bays), carried out separately for the east (ECSI), west (WCSI), and south (SCSI) coasts of the South Island (14 849 animals, CV 11%, 95% CI 11 923–18 492) (MacKenzie & Clement 2016). The most recent estimate of Māui dolphin abundance (63 dolphins aged 1+, 95% CL 57–75) is based on the 2015–2016 surveys of genetically identified individuals from the west coast North Island (WCNI) (Baker et al. 2016b). There were also two Hector's dolphins genetically identified

Table 6.1: Survey abundance estimates for Hector's and Māui dolphins by area and year. The results of the different surveys may not be directly comparable due to differences in survey methods. Studies are organised by coastal region: ECSI = East Coast South Island, NCSI = North Coast South Island, WCSI = West Coast South Island, SCSI = South Coast South Island, WCNI = West Coast North Island.

Subpopulation	Survey region	Years of survey	Method	Abundance estimate (95% confidence interval)	Reference
WCNI	Kaipara Harbour to 10 nm south of Whanganui; out to 0.43 nm*	1985	Boat strip transect	134	Dawson & Slooten 1988
	Kaipara Harbour to 10 nm south of Whanganui; out to 0.43 nm*	1985	Re-analysis of Dawson & Slooten 1998	140 (46–280)	Martien et al. 1999
	Kaipara Harbour to New Plymouth; out to 800 m from shore	1998	Boat strip transect	80	Russell 1999
	Paraparaumu and North Cape; out to 10 nm	2001/02	Aerial transect	75 (48–130)	Ferreira & Roberts 2003
	Not stated	2003	Genetic capture recapture	69 (38–125)	Baker et al. 2013
	Maunganui Bluff to New Plymouth; out to 10 nm	2004	Aerial transect	111 (48–252)	Slooten et al. 2006
	Not stated	2006	Genetic capture recapture	59 (19–181)	Baker et al. 2013
	Baylys Beach to New Plymouth	2010–2011	Genetic capture recapture	55 (48–69)	Hamner et al. 2014b
	Kaipara Harbour to Mokau River, Taranaki	2015–2016	Genetic capture recapture	63 (57–75)	Baker et al. 2016b
Entire South Island	Out to 20 nm	2010–2015	Aerial line transects	14 849 (11 923–18 492)	MacKenzie & Clement 2016
	Out to 10 nm	1997–2000	Boat and aerial line transects	7270 (5303–9966)	Slooten et al. 2004; Dawson et al. 2004
	Out to 0.43 nm	1985	Boat, strip transects	3274	Dawson & Slooten 1988
WCSI	Farewell Spit to Milford Sound; out to 20 nm	2014/15	Aerial line transects	Summer: 5490 (3319–9079) Winter: 5802 (3879–8679)	MacKenzie & Clement 2016
	Farewell Spit to Milford Sound; out to 10 nm	2000–2001	Aerial line transects	5388 (3613–8034)	Slooten et al. 2004
ECSI	Kaikōura coast	2014–2015	Genetic capture recapture	480 (342–703)	Hamner et al. 2016
	Kaikōura coast	2013	Photo-ID, mark re-capture	304 (211–542)	Weir & Sagnol 2015
	Cloudy Bay	2011–2012	Genetic capture recapture	272 (236–323)	Hamner et al. 2013
	Cloudy Bay and Clifford Bay; out to at least 16 nm	2008–2009	Aerial line transects	Summer: 951 (573–1577) Winter: 315 (173–575) Spring: 188 (100–355)	Du Fresne & Mattlin 2009
	Banks Peninsula	1989–1997	Photo-ID, mark re-capture	1,119 (744–1,682)	Gormley et al. 2005
	Otago coast; out to 400m	2010–2011	Boat line transect	42 (19–92)	Turek et al. 2012
ECSI & NCSI ECSI & NCSI	Farewell Spit to Nugget Point; out to 20 nm	2012–2013	Re-analysis of Mackenzie & Clement 2014	Summer: 9728 (7001–13 517) Winter: 8208 (4888–13 785)	MacKenzie & Clement 2016
ECSI & NCSI	Farewell Spit to Nugget Point; out to 20 nm	2012–2013	Aerial line transect	Summer: 9130 (6342–13 144) Winter: 7456 (5224–10 641)	MacKenzie & Clement 2014
	Farewell Spit to Motunau; out to 20 nm	1998/99	Boat line transect	285 (137–590)	Clement et al. 2001
ECSI & SCSI	Long Point, Fiordland to Timaru; out to 20 nm	1998/99	Boat line transect	399 (279–570)	Du Fresne et al. 2001
ECSI, NCSI, & SCSI	Farewell Spit to Long Point; out to 20 nm	1997–2000	Boat line transect	1880 (1246–2843)	Dawson et al. 2004
SCSI	Long Point, Fiordland to Nugget Point; out to 20 nm	2018	Aerial line transects	332 (217–508)	MacKenzie & Clement 2019
	Long Point, Fiordland to Nugget Point; out to 20 nm	2010	Re-analysis of Clement et al. 2011	238 (113–503)	MacKenzie & Clement 2016
	Long Point, Fiordland to Nugget Point; out to 20 nm	2010	Aerial line transects	628 (301–1311)	Clement et al. 2011
	Te Waewae Bay	2005/06	Photo-ID mark-recapture	Summer: 580 (480–700) Winter: 380 (300–500)	Rodda 2014
	Te Waewae Bay	2004/05	Photo-ID mark-recapture	Summer: 403 (269–602) Autumn: 251 (183–343)	Green et al. 2007
	Porpoise Bay	1996–1997	Photo-ID mark-recapture	48 (44–55)	Bejder and Dawson 2001

* The 1985 estimates by Dawson & Slooten (1988) were adjusted upward by a factor of five to account for the assumed proportion of the population occurring within sight of the coastal transect (out to 800 m) based on the proportion of all sightings in this zone along 5 nm transects off the South Island.

during the 2015–2016 Māui dolphin surveys. The research programmes producing these estimates are described in greater detail below.

There are a few recent genetic and photo-identification mark-recapture estimates for local Hector's dolphin populations that are valuable for understanding local population dynamics and areas of conservation concern. These estimates are more accurate when dolphins have small ranges with limited offshore dispersal allowing greater chance of sampling most of the population e.g., Porpoise Bay and Kaikōura (Bejder & Dawson 2001, Weir & Sagnol 2015, Hamner et al. 2016), but are less robust when the populations range further offshore and become less accessible e.g., Cloudy Bay (Hamner et al. 2017) as highlighted by comparisons with aerial surveys with greater coverage (Du Fresne & Mattlin 2009, MacKenzie & Clement 2014, MacKenzie & Clement 2016).

Differences in the offshore extent of survey sampling effort may account for discrepancies between current aerial survey based abundance estimates and earlier population estimates from boat-based transect surveys (e.g., Dawson & Slooten 1988, Dawson et al. 2004, Slooten et al. 2004, 2006) or from photo-ID mark-recapture studies focused on particular local populations of Hector's dolphins (Gormley et al. 2005, Turek et al. 2013).

6.2.6.1 MĀUI DOLPHIN GENETIC MARK-RECAPTURE CENSUS

Beginning in 2010–11, Māui dolphin populations have been monitored with a boat-based census every 5 years, using genetic mark-recapture methods. The 2015–16 census estimated an abundance of N = 63 animals (95% CL 57–75) for the population of Māui dolphins at least one year old (Baker et al. 2016b). These estimates are comparable to, but slightly larger than the previous estimate of N = 55 (95% CL 48–69) based on comparable genotype surveys in 2010–11 (Hamner et al. 2012b). The longer time series and higher resolution mark-recapture data informed updated demographic models and improved estimation of survival rate and population trend than presented previously (Roberts et al 2019b, Cooke et al. 2018, 2019). A repeat genetic mark-recapture census using the same method is currently in progress (in 2020–21) by the University of Auckland and Oregon State University, funded jointly by DOC and Fisheries New Zealand.

6.2.6.2 HECTOR'S DOLPHIN AERIAL SURVEY PROGRAMME

Beginning in 2010, a series of aerial surveys were conducted under MPI contracts to estimate the abundance and characterise the spatial distributions of the SCSI, ECSI, and WCSI Hector's dolphin subpopulations (Clement et al. 2011, MacKenzie et al. 2012, MacKenzie & Clement 2014, 2016; MacKenzie & Clement 2019); see Figure 6.2.

The initial SCSI aerial survey programme involved two aerial surveys undertaken during March 2010 and August 2010 between Puysegur Point and Nugget Point and out to the 100 m depth contour (Clement et al. 2011). MacKenzie & Clement (2016) reanalysed the SCSI survey data from 2014 and produced an annual average population estimate for the SCSI of 238 (s.e. 94; 95% c.i. 113–503) based on revised figures for availability. In early 2018 a repeat survey successfully obtained a lower CV in the estimate of population size by adopting higher sampling intensity in the nearshore strata and in areas of high dolphin density in Te Waewae Bay. The updated SCSI population size from MacKenzie & Clement (2019) is 332 animals (95% c.i. 217–508).

The ECSI aerial survey programme involved an initial design phase (MacKenzie et al. 2012) followed by two aerial surveys conducted over summer 2012–13 and winter 2013 between Farewell Spit and Nugget Point and offshore to 20 nm (covering about 42 677 km^2; MacKenzie & Clement 2014). A total of 354 dolphin groups were sighted in the summer, along 7156 km of transect lines, and 328 dolphin groups were sighted in the winter, along 7276 km of transect lines. MacKenzie & Clement (2016) reanalysed the ECSI survey data from 2014 and produced an annual average estimate for the ECSI of 8968 animals (s.e. 1377; 95% c.i. 6649–12 096), based on revised figures for availability. Note these estimates do not include harbours and bays, which were outside the designated survey strata.

The WCSI aerial survey programme involved two separate aerial surveys in summer 2014–15 and winter 2015 (MacKenzie & Clement 2016). The population within the WCSI survey area (about 26 333 km^2 between Farewell Spit and Milford Sound) was estimated at 5490 animals (CV = 26%; 95% c.i. 3319–9079) in summer and 5802 (CV = 21%; 95% c.i. 3879–8679) in winter. These estimates were obtained by averaging the four sets of results for each season; from two different datasets using different truncation distances and two methods of estimating

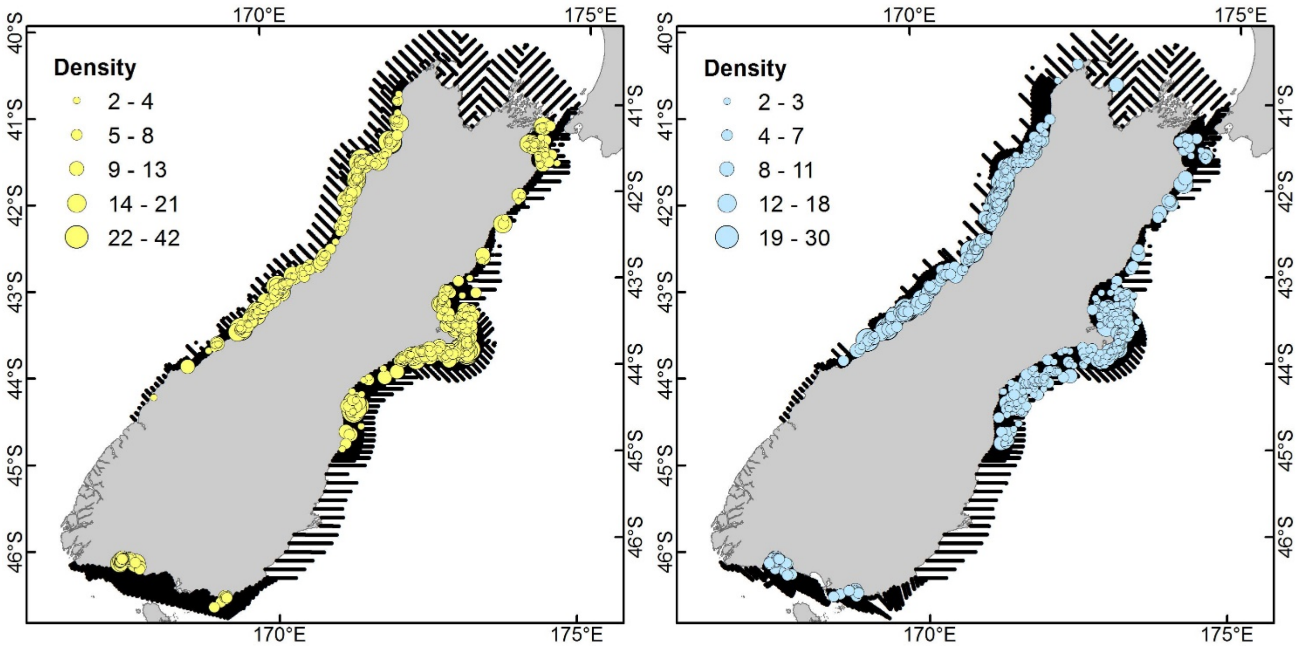


Figure 6.2: Hector's dolphin summer (left) and winter (right) sightings from the three separate abundance surveys: west coast (WCSI) completed in 2015, east and north coast (ECSI) completed in 2013, and south coast (SCSI) completed in 2010. Black lines represent the paths of aerial survey transects. Reproduced from Roberts et al. (2019a) using the outputs of MacKenzie & Clement (2016). Note that the SCSI survey was repeated in early 2018 (Mackenzie & Clement 2019).

availability (dive cycle and circle-backs). These estimates are very similar to the previous 2000–01 WCSI estimate of 5388 Hector's dolphins by Slooten et al. (2004) (CV = 21%; 95% c.i. 3613–8034), even after accounting for differences in offshore survey areas (MacKenzie & Clement 2016).

Arising from the reanalysis of the ECSI and SCSI survey data, MacKenzie & Clement (2016) estimated the total Hector's dolphin population in coastal areas around the full South Island (excluding sounds and harbours) at 14 849 animals (CV = 11%; 95% c.i. 11 923–18 492). This estimate is approximately double the previous estimate from surveys conducted in the late 1990s–early 2000s (7300; 95% c.i. 5303–9966) (Slooten et al. 2004), with the difference primarily due to the substantial number of dolphins sighted in offshore waters at distances greater than had been extensively surveyed previously, especially in ECSI (MacKenzie & Clement 2016).

Following discussion in the International Whaling Commission (IWC) Sub-committee on Small Cetaceans, in 2015 the subcommittee agreed to an inter-sessional review of the methods used in these abundance estimates (International Whaling Commission 2016a). A formal process was agreed whereby an Inter-sessional Expert Group (IEG) reviewed the abundance methodology and estimates produced by MacKenzie & Clement (2014, 2016) (International Whaling Commission 2016b).

The IEG recognised that this study accounted for many difficulties that also affect other small cetacean abundance estimation studies using aerial surveys. It commended the ambitious and often innovative work undertaken by the authors to attempt to deal with all of those issues. After a thorough review of the survey design, analyses, and results, the IEG endorsed the abundance estimates and concluded that the estimates accurately reflected the data, were derived from appropriate data collection and analysis methods, and represented the most current abundance estimate for Hector's dolphins around the South Island (such that it would be reasonable to use them to inform a management plan). The IEG also considered this study to be a step forward in the development of survey methodology more generally (International Whaling Commission 2016b).

In 2019 the aerial survey observations were used to parameterise spatial habitat models to estimate the seasonal spatial density of Hector's and Māui dolphins, a critical input to the spatial multi-threat risk assessment used to inform the update of the TMP (Roberts et al. 2019a).

6.2.7 CHANGES IN POPULATION SIZE

Change in population size can be summarised in terms of the direction of population change (i.e., increasing or decreasing), or the annual rate of population change (λ)

where $\lambda > 1$ indicates population increase, and $\lambda < 1$ indicates decline, which is used as a basis for the current domestic and international threat classification status rankings for both sub-species (Baker et al. 2019, Reeves et al. 2020).

The use of survey-based population size estimates for estimating population growth rate is hampered by changes in survey methods through time, and by the low precision of estimates (Table 6.1). A population model fitted to estimates of Māui dolphin population size estimated a slightly declining population size with reasonably high precision (λ = 0.98, 95% credible interval = 0.96–1.00) (Roberts et al. 2019b). This assessment found that Māui dolphin population change was primarily driven by female survival, which was estimated to be around 5% higher than for males.

The rate of population change can also be inferred indirectly with population simulations using prior distributions of all required demographic rates, i.e., survival and reproductive rate at age. A demographic assessment fitted to photo-ID observations of Hector’s dolphins inside the Banks Peninsula Marine Mammal Sanctuary (BPMMS) found that their population trajectory is likely to be stable since the establishment of the sanctuary (λ = 1·00, 95% CI = 0·93–1·05) (Gormley et al. 2012). More precise estimates of calving interval were identified as the best way of reducing uncertainty in population growth using this method (Gormley 2009).

Population trajectory, and population status relative to historical values, have also been estimated indirectly using logistic population growth models that incorporate estimates of historical commercial fishery deaths (Martien et al. 1999, Burkhart & Slooten 2003, Slooten 2007, Slooten & Dawson 2010). The latest published analysis estimated the population size of Hector’s dolphin in 2009 to be 27% of the 1970 estimate, and that the Māui dolphin was the most depleted subpopulation (Slooten & Dawson 2010). However, these assessments used population abundance estimates for the ECSI population that were later shown to underestimate actual population size by a factor of 3–5 relative to comprehensive aerial survey derived estimates of comparable areas. As a consequence these analyses have greatly over-estimated the vulnerability of dolphins to capture in commercial set nets (and, hence, historical fishery-related deaths as a proportion of total population) and will therefore estimate a lower status relative to un-impacted levels than would be obtained with comparable models using updated population estimates (J Roberts unpublished data). The assessment by Slooten & Dawson (2010) (and earlier iterations) is also inconsistent with the outputs of the most recent spatial risk model (Roberts et al. 2019a), which found that the median estimates of commercial fisheries deaths since 1992–93 would be insufficient to prevent population recovery to 90% of un-impacted levels, for both Hector’s and Māui dolphins. However, current population trend and status depend also on assumptions about non-fishery threats and will be affected by assumptions regarding historical depletion, including from recreational fisheries and from commercial fishing prior to the establishment of the Quota Management System (QMS), when effort levels were higher and less regulated. For example Lallemand et al. (2008) reported that set net fishing effort over large portions of the ECSI declined by more than 80% following the establishment of the QMS in 1986, but spatially precise effort location data are not available for this period.

Ongoing research under Fisheries New Zealand project PRO2019-11 will estimate the spatial distribution of historical set net fishing effort in the period prior to 1992–93, for which effort data were unavailable to the spatial risk model described by Roberts et al. (2019a). The historically reconstructed effort data can then be used to estimate population status for Hector’s dolphin subpopulations, by applying the SEFRA modelling approach to historical fishing effort patterns from the time when monofilament nets were first employed.

6.2.8 SUBPOPULATION STRUCTURE

For purposes of the spatial risk assessment used to inform the update of the Hector’s-Māui dolphin Threat Management Plan (Roberts et al. 2019a), the South Island Hector’s dolphin population is divided into four subpopulations, corresponding to the east coast, south coast, west coast, and north coast, as shown in Fig 6.3. The existence of a genetically distinct NCSI population is suggested based on genetic evidence (Baker et al. 2017), but requires a higher sample size to be confirmed.

In the risk assessment by Roberts et al. (2019a), the Māui dolphin subpopulation is presumed to occupy the area from Taranaki in the south to Cape Reinga in the north. The area from Taranaki southward to the Kāpiti Coast is considered to be a potential habitat for dolphins expanding their range, and/or a transition zone for dolphins moving between the WCNI subpopulation and the South Island. The remainder of the North Island is presumed to have no current resident population, but the fisheries risk assessment can still be used to evaluate what the risk would be to any dolphins occupying preferred habitats in those areas (see below).

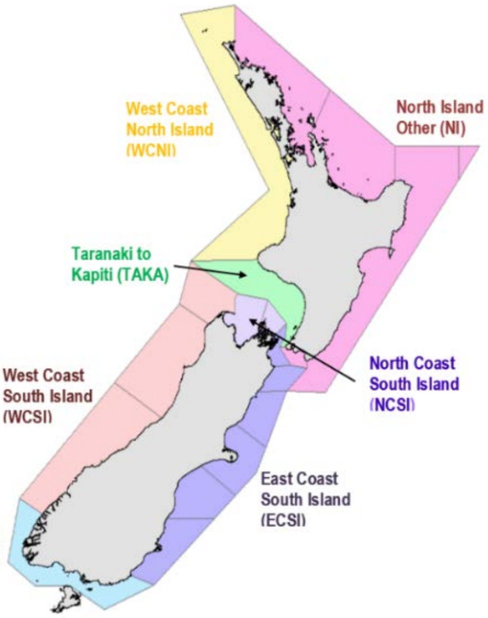


Figure 6.3: Boundaries designating Hector’s and Māui subpopulations for purposes of spatial risk assessment (Robert et al. 2019a). The number of animals in each subpopulation was estimated based on aerial surveys (for Hector’s dolphins) or genetic census (for Māui dolphins). Subpopulation zones with no known year round population (‘Taranaki to Kāpiti’ and ‘other North Island’) were assigned arbitrary low numbers of dolphins so that potential risk to transient or future populations could be estimated in the risk assessment.

6.2.9 SPATIAL DOLPHIN DENSITY ESTIMATION

The seasonal (summer and winter) spatial abundance of Hector’s and Māui dolphins was estimated as part of the spatial risk assessment of threats to Hectors and Māui dolphins (Roberts et al. 2019a) (see section 6.4). The primary spatial abundance information for predicting the coastal abundance of Hector’s and Māui dolphins came from a series of summer and winter aerial line-transect surveys for estimating the abundance and spatial distribution of Hector’s dolphins, conducted around the South Island of New Zealand between 2010 and 2015 (MacKenzie & Clement 2014, 2016). Habitat models were fitted to aerial survey observations (Figure 6.2) related to candidate spatial habitat layers, including physical variables (e.g., depth or turbidity) and biotic variables (e.g., the modelled prevalence of key prey species).

The habitat model used to estimate the spatial density of Hector’s and Māui dolphins included satellite derived seasonal turbidity and trawl survey derived prevalence of ahuru (*Auchenoceros punctatus*) (a key prey species, Miller et al. 2013) as predictors. The inclusion of turbidity as the primary model term is consistent with the assessments by Bräger (1998), Torres et al. (2013), and Stephenson et al. (2020), who all found water turbidity to be a strong predictor of Hector’s and Māui dolphin presence and abundance.

The aerial survey parameterised model could not be used to estimate spatial density inside the harbours of the WCNI, which were much more turbid than the South Island regions where the model was fitted, and where physical features such as sandbars or tidal mudflats may affect dolphin distributions at scales smaller than the habitat model can predict. For these reasons, the relative spatial density of Māui dolphins in WCNI harbours was estimated using a separate habitat preference model fitted to validated public sightings data and an aerial survey of spatially resolved boat density as a proxy for spatial public sighting ‘effort’, related to locational/habitat based variables. This model also found turbidity to be the strongest predictor of sightings density and estimated a very low relative abundance inside harbours, where recreational boat density is high, but validated dolphin sightings are rare (Figure 6.4).

Roberts et al. (2019a) give a full description of the methods, data, and assumptions underlying the spatial dolphin density estimation. Section 6.5.6 below identifies particular locations in which the spatial predictions may be more uncertain, with implications for risk assessment outputs.

The final spatial dolphin density estimate was obtained by combining the habitat preference based estimate in the South Island in coastal waters of the North Island with the public sightings based estimate in WCNI harbours. Spatial abundance was rescaled for each of the subpopulation areas defined in Figure 6.3, using population size estimates from aerial surveys (for Hector’s dolphins) or genetic mark-recapture census (for Māui dolphins) as described above. The composite spatial abundance predictions for Hector’s and Māui dolphins are shown in Figure 6.4. The resulting spatial density prediction achieved a high degree of correspondence with spatial patterns of public sightings and commercial fishery observer sightings of both Hector’s and Māui dolphins (see Figure 6.5 and appendix 7 of Roberts et al. 2019a), indicating that the habitat model accurately represented the true habitat requirements of both sub-species, despite being fitted primarily to Hector's dolphin observations.

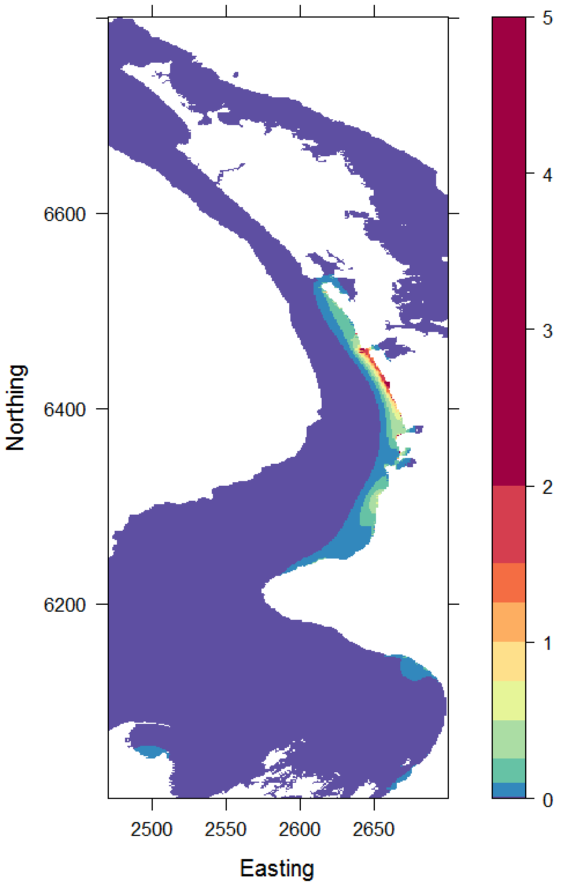


Figure 6.4: Estimated spatial density of Hector's and Māui dolphins off the west coast of the North Island from a predictive model fitted to boat-based validated public sightings. From Roberts et al. (2019a).

6.2.10 THREATS TO HECTOR'S AND MĀUI DOLPHINS

6.2.10.1 FISHERIES BYCATCH

Fisheries bycatch, particularly in recreational and commercial set net fisheries and to a lesser extent in commercial trawls, is a known threat to Hector's and Māui dolphins. Hector's and Māui dolphin bycatch is thought to have increased rapidly with the widespread adoption of monofilament set nets in the 1970s and 1980s and declined thereafter (e.g., Dawson 1991, Dawson and Slooten 1993, Martien et al. 1999, Duignan et al. 2003, Currey et al. 2012, Abraham et al. 2017). Commercial and recreational set net fishing remains a threat to dolphin populations in locations where the spatial distribution of dolphins (e.g., Figure 6.5) overlaps the spatial distribution of set net and trawl fishing effort.

Observations and records of fisheries bycatch are summarised in section 6.3. These observations may provide valuable information about the nature of fisheries captures, but fisher-reported bycatch rates in isolation are not a reliable means of estimating total commercial fisheries deaths, because it is likely that not all fishers will voluntarily report all bycatch events. Government fisheries observers are deployed on a proportion of commercial fishing vessels, but historically observer coverage has been low in inshore fisheries except in locations of particular concern (such as the WCNI set net fishery since 2012, due to the urgent conservation status of Māui dolphins). Where observer coverage is low, it may not be representative of total fishing effort in space and time, so it is necessary to correct for the effects of potential coverage bias in the estimation of fisheries risk. The SEFRA method (Chapter 3) is designed to achieve this; the extent and magnitude of the fisheries risk to dolphin subpopulations has been estimated using this approach, described in section 6.4.

6.2.10.2 DISEASE

The awareness of disease as a potential serious threat to Hector's and Māui dolphins has emerged only recently, since the last update of the TMP in 2012 (e.g., see Currey et al. 2012).

There have been 5 Māui dolphin and 50 Hector's dolphin necropsies undertaken by veterinary pathologists at Massey University. Analysis of samples collected from beach-cast or entangled/bycaught Hector's and Māui dolphins revealed that disease was a major cause of death, followed by maternal separation (i.e., when a calf is separated from its mother – this is a primary cause of calf mortality), and then bycatch (Roe et al. 2013). Infectious diseases, including brucellosis, pneumonia, toxoplasmosis, and tuberculosis, were identified as the cause of death for 53% (n = 23/43) of dolphins where cause of death could be determined.

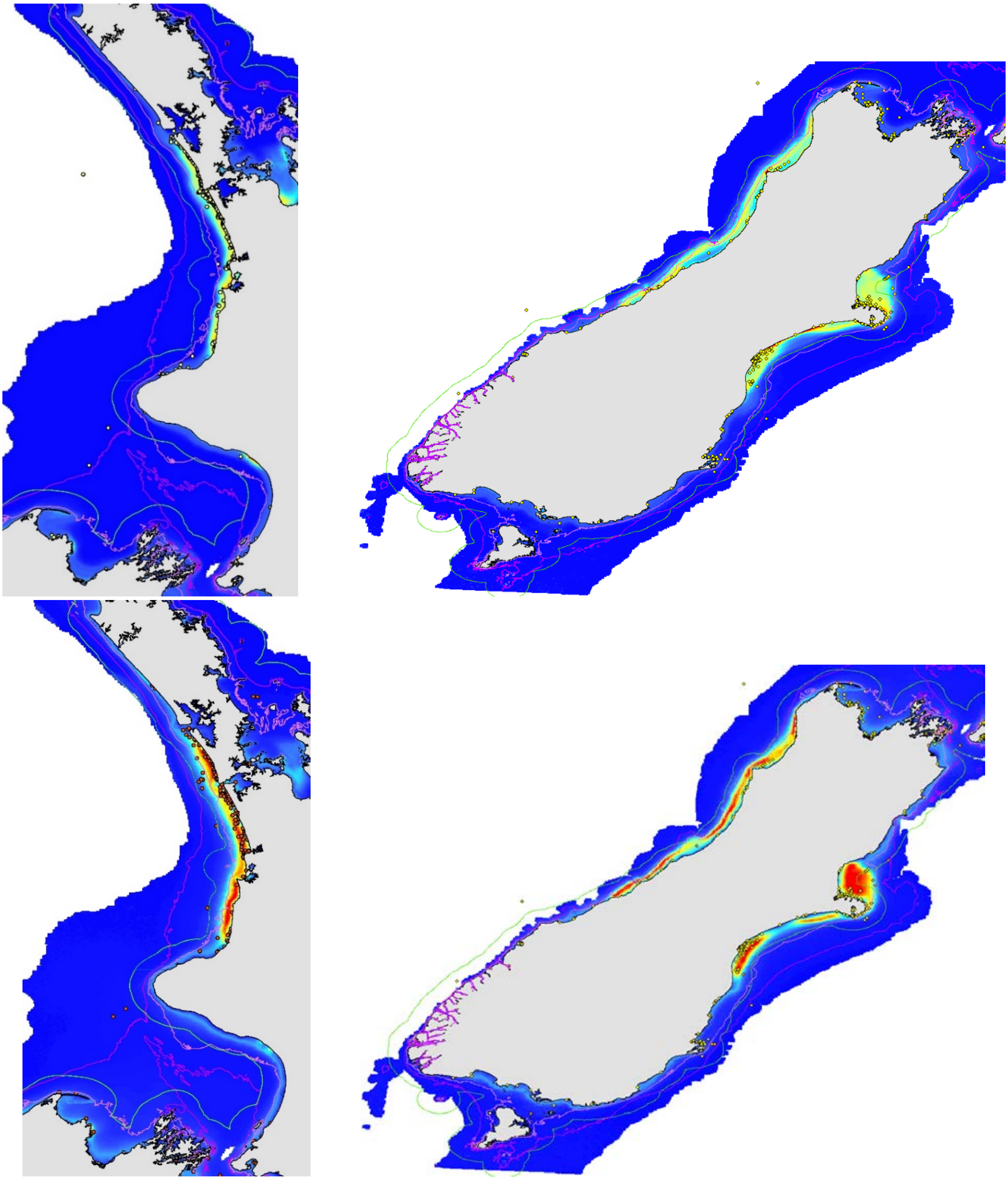


Figure 6.5: Estimated spatial density of Hector's and Māui dolphins in summer (top) and winter (bottom) used in the spatial multi-threat risk assessment by Roberts et al. (2019a). Also shown are the 50 m and 100 m depth contours (in purple), the Territorial Sea boundary (in green), and the locations of validated public sightings.[The DOC sightings confirmation process is described at https://www.doc.govt.nz/globalassets/documents/conservation/native-animals/marine-mammals/mauis-validation-system.pdf.]

The main disease of concern for Hector's and Māui dolphins is toxoplasmosis. Toxoplasmosis is a disease caused by infection with a single-celled parasite *Toxoplasma gondii*, which is capable of infecting all bird and mammal species and for which the domestic house cat (*Felis catus*), including owned, stray, and feral cats, is the only definitive host in New Zealand. It is thought that toxoplasmosis oocysts in cat faeces are transmitted to the ocean via waterways and accumulate up the marine food chain through filter feeding animals (such as shellfish or small pelagic fish that filter plankton) and then to dolphins ingesting infected prey (Massie et al. 2010).

Of the 31 non-fishery related deaths of non-calf dolphins, recorded by the Massey University SoVS Pathology Database between 2007 and 2018, nine died from toxoplasmosis of which seven (78%) were females (ECSI = 5; WCSI = 2; WCNI = 2; see also Table 6.4 below). Based on identification of toxoplasma in the tissues of bycaught and beach-cast dolphins, the majority (61%) were found to be infected (Roe et al. 2013). Factors influencing whether or not an infection causes disease (and/or becomes fatal) are poorly understood, but are related to a number of factors associated with the immune response of the host (reviewed by Roberts et al. in review). Also, toxoplasma virulence is known to be influenced by host and parasite genetics, e.g., some genetic strains of toxoplasma are more lethal than others for certain host species (for example, California sea otters (Miller et al. 2004; Kreuder et al. 2003; Conrad et al. 2005; Shapiro et al. 2019)). It may be that nutritional stress or other factors influencing immune system function can also cause dormant toxoplasma infections to become active (see below). Worldwide, toxoplasmosis is recognised as a threat to a wide range of marine and terrestrial wildlife species, especially in parts of Australia and the Pacific region (Roberts et al. in review, Barbieri et al. 2016; Work et al. 2000). Notably, these are often locations where the native fauna did not evolve in the presence of cats, as in New Zealand. Further research to understand the effects of toxoplasmosis on Māui and Hector's dolphins is being planned between agencies, led by the Department of Conservation.

Of other diseases identified in necropsy results, pneumonia was the second most common non-fishery related cause of death for non-calf dolphins (13%, n = 4/??), followed by brucellosis (6%, n =2/31, both females). Brucellosis is associated with deaths and foetal loss in mammals, and an analysis of Hector's and Māui dolphins revealed 26% (n = 7/27) tested positive for Brucella (Buckle et al. 2017). Like toxoplasmosis, dolphins can carry this disease without it causing death, but, in addition to the two female Hector's dolphin deaths from brucellosis, there was also a neonate Māui dolphin death. The form of Brucella that killed two of the dolphins had the greatest similarity to *Brucella pinnipedialis* – typically reported in seals, but it is likely that there is a Pacific form of marine Brucella not yet fully described. Since that study, in 2018, a female Māui dolphin died from septicaemia after her near-term foetus died from brucellosis and she was unable to birth the stillborn calf (Dr Wendi Roe, Massey University, unpublished data).

'Normal' or background infection levels of these diseases in living dolphins is poorly known, as blood and/or tissue samples are required to test for *Toxoplasma gondii* and Brucella infection. Although disease is normal within the marine environment, the presence of a specific cat borne disease is of concern, as is the fact that both of these diseases appear to disproportionately affect female dolphins, and that 2 of 9 toxoplasmosis deaths and 2 of 4 Brucella-attributable deaths were of Māui rather than Hector's dolphins, despite their much smaller population size.

Reflecting the results of the spatial risk assessment by Roberts et al. (2019a) below, and the Māui dolphin population model projections of Cooke et al. (2019) below, toxoplasmosis in particular has been identified as a major priority for further research and for conservation action. The Department of Conservation has prepared a Toxoplasmosis Action Plan outlining priorities to guide this work.

6.2.10.3 TROPHIC AND/OR CLIMATIC EFFECTS

To date (June 2020), there has been no formal assessment of the potential indirect effects of fishing on Hector's and Māui dolphins, e.g., via trophic competition. All of the dolphins' main prey species (e.g., Miller et al. 2013) are either targeted or are regular bycatch of commercial fisheries, but the average size of the fish appearing as prey in dolphin stomachs is generally smaller than adult size classes that are routinely targeted or selected by fishing gear (Weir 2018). A rigorous evaluation of potential trophic effects of fishing on prey availability for dolphins would likely require spatially explicit estimates of fisheries extractions at scales relevant to individual dolphin movements and existing closed areas, considering both the size selectivity of fisheries removals and the potential for recruitment overfishing.

Climate change and/or climatic variability is likely to affect dolphins, in particular because inter-annual changes in sea temperature are likely to affect the distribution or availability of prey species or influence terrestrial run-off (Shears & Bowen 2017). It is not known how changes in spatial patterns of water turbidity or prey distributions will affect Hector's and Māui dolphins. They have the ability to disperse to other areas, and they have a varied diet so there may be shifts in habitat use and range, but the species' history of small ranges and high site fidelity may impose a behavioural limit on their ability to move, which ultimately may affect their reproductive success. Effects of climate change are likely to be greater for subpopulations with small home ranges.

Roberts et al. (2019a) estimated that for all suitable prey species, the total abundance of available prey species was many times lower in WCNI relative to suitable Hector's dolphin habitats around the South Island. Improved prey abundance modelling considering also the size distribution of the available prey may provide additional insight of the extent to which Māui dolphins may confront a shortage of suitable prey relative to Hector's dolphins. Weir (2018) notes that their income breeding strategy and high energetic demands during pregnancy may make Hector's and Māui dolphins particularly vulnerable to factors that reduce or temporarily disrupt their regular access to preferred prey, potentially affecting their reproductive success or susceptibility to disease.

6.2.10.4 OTHER ANTHROPOGENIC THREATS

Underwater noise can cause physical injury and disturbance to dolphins. Noise exposure can be estimated using underwater sound propagation modelling (e.g. McPherson et al. 2019), but the actual effects of different levels and types of sound on marine mammals are poorly understood (Forney et al. 2017, Leunissen & Dawson 2018, Lucke et al. 2019). Disturbance may be short-term and/or episodic (e.g., noise from seismic surveys, pile driving, drilling or mining, research activities, or vessel traffic), but may have a cumulative impact and/or a habitat displacement effect with consistent or repeated exposure.

Boat strikes are not thought to be a major cause of death but there has been one confirmed death, a Hector's dolphin calf in Akaroa harbour in 1999 (Stone & Yoshinaga 2000, DOC 2020a). Commercial dolphin-watch tourism may have negative effects on cetaceans (e.g., Martinez et al. 2012); these activities are regulated by the Department of Conservation.

Most marine pollutants have sub-lethal effects that may be difficult to detect. By global standards, the levels of pollutants such as DDT and PCBs in New Zealand waters are low, but their coastal habitat and preferred fish prey may make Hector's and Māui dolphins more exposed to accumulating pollutants than offshore species (Stockin et al. 2010; Jones et al. 1996, 1999) and Māui dolphins in particular may be especially vulnerable, because their spatial distribution is largely confined to turbid waters affected by freshwater river plumes that are highly contaminated (Hunt & Jones 2020).

6.2.10.5 NATURAL CAUSES OF DEATH

Hector's and Māui dolphins are vulnerable to predation by sharks and killer whales. Most predation events in New Zealand are attributed to seven-gill sharks or white sharks (Cawthorn 1988) but other large sharks may also prey upon these small dolphins (Heithaus 2006). Because these are naturally occurring events they are not managed as 'threats' but the spatial distribution of seven-gill and white shark populations is non-uniform, so understanding the level of risk from shark predation and patterns of overlap between sharks and dolphins helps us to understand cumulative threats to different dolphin subpopulations.

A major natural cause of death for Hector's and Māui dolphin calves is maternal separation (i.e., when a dependent calf is separated from its mother). As a cause of death in necropsied individuals, it is second only to disease (Roe et al. 2013); the rate at which this occurs is possibly exacerbated by extreme weather conditions (DOC & MFish 2007, MPI & DOC 2012).

6.2.11 CONSERVATION BIOLOGY AND THREAT CLASSIFICATION

Threat classification is an established approach for identifying species at risk of extinction (IUCN 2013). The risk of extinction for Hector's and Māui dolphin has been assessed under two threat classification systems: the New Zealand Threat Classification System (Townsend et al. 2008) and the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species (IUCN 2013).

The IUCN classifies Māui dolphin as Critically Endangered under criteria A4c,d and C2a(ii)[5] due to an ongoing or

---

[5] A taxon is listed as 'Critically Endangered' if it is considered to be facing an extremely high risk of extinction in the wild. A4c,d refers to a reduction in population size (A), based on an observed, estimated, inferred, projected or suspected reduction of ≥ 80% over any 10-year or three-generation period (whichever is longer up to a maximum of 100 years (3)); with the reduction being based on a decline in area of occupancy, extent of occurrence and/or quality of habitat (c); or actual or potential levels of exploitation (d; IUCN 2010). C2a(ii) refers to a population size estimated to

projected decline of greater than 80% over three generations, and there being fewer than 250 mature individuals remaining (Reeves et al. 2020). Hector's dolphin is classified by the IUCN as Endangered under criterion A4d[6] due to an ongoing or projected decline of greater than 50% over three generations (Reeves et al. 2020).

Under the New Zealand Threat Classification System (Baker et al. 2019), Māui dolphin is classified as Nationally Critical, the most threatened status, under criterion A(1), with the qualifier Conservation Dependent (CD)[7]. Hector's dolphin is classified as Nationally Vulnerable under criterion D(1/1), with the qualifier Conservation Dependent (CD)[8].

6.3 FISHERIES INTERACTIONS

6.3.1 DATA FROM RECOVERED CARCASSES AND FISHER-REPORTED CAPTURES

Hector's and Māui dolphins have been caught in inshore commercial and recreational set net fisheries and in inshore trawl fisheries since at least 1973 (DOC 2020a; Baker 1978). Beach-cast carcasses are frequently reported by members of the public; floating carcasses may be reported by fishers or other boaters; fishers are also required to report incidental captures. The Department of Conservation maintains a Hector's and Māui dolphin incident database in which all such deaths are recorded including the cause of death where this can be determined (DOC 2020a[9]). A summary of known, probable, or possible fisheries deaths from this database is shown in Table 6.2. Incidental fisheries mortalities have been documented throughout the species range but the greatest number of reports are from the east coast South Island.

Nineteen individual Hector's dolphins were reported caught in trawl fisheries between 1973 and 2008, with seven since 2008, in 13 separate capture incidents reported by fishers (Table 6.2; DOC 2020a). Hector's dolphin captures in trawl nets include an individual caught in a trawl targeting red cod in Statistical Area 022 in 1997–98 (Starr & Langley 2000), the capture of three Hector's dolphins in a trawl in Cloudy Bay in 2006 (DOC & MFish 2007), and the capture of three dolphins in each of two separate inshore trawl events north of Banks Peninsula, in December 2018 and February 2019. Further investigation of the trawl gear configurations and vessel characteristics of fishing events in which dolphins were captured may prove useful to evaluate the extent to which gear design may affect dolphin catchability.

There is evidence of frequent bycatch of Hector's dolphins in set nets at Banks Peninsula extending back to at least the mid-1970s (Dawson 1991). Interviews with commercial fishers, voluntary reports by recreational fishers, and carcass retrieval indicated at least 230 deaths in set nets between 1984 and 1988 (Dawson 1991). Two hundred of these were reported by commercial fishers, who frequently supplied carcasses for dissection. A further 24 mortalities were reported by or attributed to amateur set net fishers. Six net-marked carcasses were recorded as "unknown net". The highest number of Hector's dolphin bycatch deaths reported annually by Dawson (1991) was 95 animals, in the 1985/86 season. Total deaths declined in the following two years (to 44 and 29 deaths, respectively), perhaps related to declining total effort levels coincident with the establishment of the QMS, as reported by Lallemand et al. (2008).

The DOC incident database records at least 45 Hector's or Māui dolphins were caught in commercial set nets from 1921 to 2008, and 12 since 2008. In recreational set nets, 21 confirmed deaths were recorded for 1921–2008 and 5 since 2008. Note however that a number of beach-cast

---

number fewer than 250 mature individuals (C); with a continuing decline, observed, projected, or inferred, in numbers of mature individuals (2); and a population structure (a) with at least 90% of mature individuals in one subpopulation (ii; IUCN 2013).

[6] A taxon is listed as 'Endangered' if it is considered to be facing a very high risk of extinction in the wild. A4d refers to a reduction in population size (A), based on an observed, estimated, inferred, projected or suspected reduction of ≥ 80% over any 10-year or three-generation period (whichever is longer up to a maximum of 100 years (3)); with the reduction being based on actual or potential levels of exploitation (IUCN 2013).

[7] A taxon is listed as 'Nationally Critical' under criterion A(1) when evidence indicates that there are fewer than 250 mature individuals, regardless of population trend and regardless of whether the population size is natural or unnatural (Townsend et al. 2008).

[8] A taxon is 'Nationally Vulnerable' under criterion D (1/1)when evidence indicates that the total population size is 5,000-20,000 mature individuals and there is an ongoing or predicted population decline of 30-70% over three generations, (Townsend et al. 2008).

[9] https://www.doc.govt.nz/our-work/hectors-and-maui-dolphin-incident-database/

carcasses were attributed to 'unknown set nets' or 'unknown nets' during these time periods; these will mostly reflect beach-cast carcasses with net marks, that is, animals that may have drowned in either recreational or commercial nets. Incidental captures have most frequently occurred in commercial set nets targeting rig (*Mustelus lenticulatus*), elephant fish (*Callorhynchus milli*), and school shark (*Galeorhinus australis*) (Dawson 1991, Baird & Bradford 2000), and in recreational nets set for flounder (*Rhomboselea sp.*) and moki (*Latridopsis ciliaris*) (Dawson 1991).

There have been four known incidents of Hector's dolphins becoming entangled in buoy lines of pots set for crayfish (*Jasus edwardsii*), all from Kaikōura (Dawson 1991; DOC & MFish 2007, DOC 2020a).

Numbers of dolphin deaths recorded in the DOC incident database are not representative of total fisheries bycatch rates. Carcasses may not be reported by fishers, may not wash ashore, may not be recovered, or may not show evidence of interaction with fishing gear (Slooten 2013). Spatial and seasonal detection bias will affect the probability that carcasses will be reported, with carcasses more likely to be reported in summer, in locations where fishing occurs closer to shore, and closer to major population centres and thoroughfares.

The information in the incident database (Table 6.2) provides only a biased indication of incidental captures. It is clear from this information, however, that incidental captures may occur in all areas where the distribution of Hector's and Māui dolphins overlaps with the distribution of fishing effort. Where overlap occurs, the rate at which dolphins are captured per unit of overlap (as a proxy for encounter rate) can be estimated using fisheries observer programmes, and potentially video monitoring (see below).

Table 6.2: Numbers of fishing-related deaths of Hector's and Māui dolphins 1921–2008 and 2008–16 by cause of death and region as listed in the DOC Incident Database (2017a). ECSI = East Coast South Island, WCSI = West Coast South Island, SCSI = South Coast South Island, WCNI = West Coast North Island. See footnotes for explanation of probability categories as detailed in the database. (Continued next page)

	Cause of death	ECSI	WCSI	SCSI	NCSI	WCNI	Unknown subpopulation
From 1921 to June 2008							
Known entanglement (bycatch)[10]	Commercial set net	41	2	0	0	0	2
	Recreational set net	12	9	0	0	0	0
	Unknown set net	15	6	0	0	2	1
	Trawl net	15	4	0	0	0	0
Probable entanglement[11]	Commercial set net	0	0	0	0	0	0
	Recreational set net	0	0	0	0	0	0
	Unknown set net	1	4	0	0	0	0
	Unknown net	8	4	1	0	1	0
Possible entanglement[12]	Commercial set net	0	0	0	0	0	0
	Recreational set net	1	0	0	0	0	0
	Unknown set net	16	10	0	0	0	0
	Unknown net	16	7	1	0	2	0
From July 2008 to March 2020							
Known entanglement[13]	Commercial set net	11	0	0	0	1	0
	Recreational set net	1	1	0	0	0	0
	Trawl net	7	0	0	0	0	0
Probable entanglement[14]	Recreational set net	3	0	0	0	0	1
	Unknown set net	1	1	0	1	0	0
Possible entanglement[15]	Commercial set net	1	0	0	0	0	0

---

[10] Animal was known (from incident report) to have been entangled and died.

[11] As read from pathology report, or presence of net marks on body and a mention of this in incident report.

[12] As read from pathology report, or presence of net marks on body and a mention of this in incident report.

[13] Animal was known (from incident report) to have been entangled and died.

[14] As read from pathology report, or presence of net marks on body and a mention of this in incident report.

[15] As read from pathology report, or presence of net marks on body and a mention of this in incident report.

6.3.2 DATA FROM FISHERIES OBSERVERS

Fisheries observers record incidental captures of protected species including Hector's and Māui dolphins, on a proportion of commercial set net and commercial trawl fishing effort. These data are used to inform statistical models to estimate total captures across all fishing effort. Hector's and Māui dolphin captures recorded by fisheries observers are summarised in Table 6.3.

Because historical observer coverage in inshore fisheries has often been very low, simply scaling up from observed capture rate to estimate total captures yields estimates with unknown biases and very wide statistical confidence intervals. For example Baird & Bradford (2000) noted that the lack of information on the depth and position of commercial trawl effort and low observer coverage precluded any estimation of the total number of Hector's dolphins caught in trawl nets. Furthermore estimates from spatially blind models cannot be used to inform the design of spatial protection to reduce dolphin captures. For these reasons, to inform the update of the dolphin TMP, in 2019 these data were used in a spatially explicit risk assessment that estimates captures as a function of the overlap between dolphins and fishing effort, to correct for spatio-temporal bias arising from heterogeneous animal and fishing effort distributions, and non-representative fishing observer coverage.

Table 6.3: Observed commercial fishery captures of Hector's dolphin by fishing year from 1995–96 to 2016–17. All observed captures were from the east coast of the South Island.

	Set net			Inshore trawl		
Fishing year	Alive	Dead	Total	Alive	Dead	Total
1995–96	0	0	0	0	0	0
1996–97	0	0	0	0	0	0
1997–98	2	6	8	0	1	1
1998–99	0	0	0	0	0	0
1999–00	0	0	0	0	0	0
2000–01	0	0	0	0	0	0
2001–02	0	0	0	0	0	0
2002–03	0	0	0	0	0	0
2003–04	0	0	0	0	0	0
2004–05	0	0	0	0	0	0
2005–06	0	0	0	0	0	0
2006–07	0	1	1	0	0	0
2007–08	0	1	1	0	0	0
2009–10	0	2	2	0	0	0
2010–11	0	0	0	0	0	0
2011–12	0	0	0	0	0	0
2012–13	1	0	1	0	0	0
2013–14	0	1	1	0	0	0
2014–15	0	0	0	0	0	0
2015–16	0	0	0	0	0	0
2016–17	0	1	1	0	0	0
2017–18	0	0	0	0	0	0
2018–19	0	0	0	0	0	0
Total	3	12	15	0	1	1

6.3.3 ELECTRONIC MONITORING

In addition to data gathered by scientific observers, electronic monitoring of inshore set net and trawl fisheries has been trialled to detect dolphin captures. In the 2012–13 year, the inshore set net fishery operating in Statistical Areas 022 and 024 was observed simultaneously by observers and electronic monitoring. During that time, at least two Hector's dolphins were captured, with one released alive. McElderry et al. (2007) describe another electronic monitoring trial that observed 89 set net events and 24 trawls off the Canterbury coast in the 2003–04 fishing year. Two Hector's dolphin captures were recorded in the set nets, reflecting a similar catch rate to previous estimates using data from observers. Observers and electronic monitoring were also deployed simultaneously in the Timaru set net fishery in 2012–13 (Archipelago Marine Research Ltd 2013) and observers were deployed again in 2013–14. One confirmed and one probable capture of Hector's dolphins were observed. These trials illustrate the potential to use electronic monitoring to increase observer coverage in inshore fisheries for purposes of managing risk to dolphins. New camera deployments are planned or underway to further develop this capability.

6.4 SPATIALLY EXPLICIT MULTI-THREAT RISK ASSESSMENT

In 2018–19 a team of New Zealand scientists collaborated to produce a comprehensive spatially explicit multi-threat risk assessment to Hector's and Māui dolphins (Roberts et al. 2019a), applying a customised adaptation of the SEFRA method described in Chapter 3 of this volume.

6.4.1 METHOD OVERVIEW

The spatial risk model was based on the SEFRA method, in which an animal's exposure to a particular threat, e.g., a fishing method, in space and time is expressed a function of the spatial overlap between the threat distribution and the animal distribution. The likelihood of impact per unit overlap, e.g., the probability of capture or death per encounter with a fishing event, can then be estimated empirically using fisheries observer data (for fishing threats) or other data indicative of cause of death (for lethal non-fishery threats). Because impacts are expressed in terms of probability of death at the scale of individual animals and individual threat events which are located in space, impacts (deaths) are additive in space and also additive across multiple threats to yield population-level risk at any spatial scale. Risk is expressed as a ratio between a threat-specific or cumulative estimate of deaths in the numerator and a PST or 'Population Sustainability Threshold' in the denominator. The PST reflects biological characteristics affecting the species' ability to sustain impact, and also a tuning factor that corresponds to a defined population outcome (a policy decision). See Chapter 3 for a fuller description of the SEFRA method.

6.4.1.1 COMMERCIAL FISHERIES RISK

Estimation of commercial fishery annual deaths and risk in the Hector's-Māui dolphin risk assessment was based on the spatial overlap of fishing events with the estimated summer/winter spatial abundance of Hector's and Māui dolphins (Figure 6.5). Two commercial fishery groups were defined: inshore set net fisheries and inshore trawl fisheries. For each method, annual deaths and risk were estimated at the sub-species (i.e., Hector's vs. Māui dolphin) and subpopulation levels (e.g., ECSI, WCSI, as shown in Figure 6.3).

This assessment included cryptic mortality and post-release survival priors specific to observer-recorded Hector's and Māui dolphin captures in commercial set net and trawl fisheries (see appendix 10 of Roberts et al. 2019a).

6.4.1.2 LETHAL NON-FISHERY THREATS

For demonstrably lethal non-commercial fishery threats (but excluding recreational fishing), e.g., toxoplasmosis, predation, and others, annual deaths were estimated using a multi-threat extension of the SEFRA approach. Briefly, this approach partitioned residual deaths (total annual deaths minus commercial fishery deaths) in accordance with the attributed primary causes of death from necropsy records from 2007 to 2018 (see Table 6.4). The necropsy sample excluded:

- known/probable/possible bycatch deaths — which comprised an unknown composition of commercial fishery and recreational fishing deaths and, for commercial fisheries, the standard SEFRA approach was a more direct means;
- calves — for which there were no estimates of annual survival for estimating total annual deaths; and
- individuals for which a 'poor' confidence rating was attributed to the diagnosed cause of death.

The resulting subset used in the risk assessment (Table 6.5) was primarily composed of dolphins that were found washed up dead on the beach (beach-cast), with a smaller number of dead dolphins found floating at sea. The extent to which this sample may be biased due to differential carcass detection rates for different causes of death was evaluated using sensitivities, and is discussed further below.

The risk model estimated posterior distributions of annual deaths for each of toxoplasmosis (the primary non-fishery cause of death, and with an indirect anthropogenic origin), predation events (considered to have a high potential for undetected mortalities, tested via sensitivities), and an 'other' group of all other non-fishery causes of death (most of which may constitute 'natural mortality'). Subpopulation-specific estimates are shown in Table 6.6 and Figure 6.10.

A "predation sensitivity" was undertaken to assess the sensitivity of risk model estimates to assuming an arbitrary ten-fold reduction in the detection probability of predation events. This has the effect of increasing annual deaths from predation and reducing the estimates of deaths from toxoplasmosis and "other" non-fishery causes of death.

Exposure to toxoplasmosis and predation threats were mapped in space, using estimates of the relative spatial density of *Toxoplasma gondii* parasite oocysts (from the combined outputs of a cat density model and a hydrological model) and of predation by broadnose sevengill sharks (*Notorynchus cepedianus*) (modelled from commercial set net fishery catch and effort records). The estimated spatial overlap of toxoplasmosis and predation mortalities with Hector's and Māui dolphins was then used to estimate subpopulation-specific annual deaths for these non-fishery causes of death.

6.4.1.3 NON-LETHAL THREATS

For non-lethal threats (potentially including lethal threats that have not yet appeared in the necropsy records) that can still be resolved spatially, an alternative approach was taken. Spatial overlap with non-lethal threats was presented in two different ways:

1. Mapping of relative overlap between spatial dolphin abundance and spatial threat intensity. This highlighted areas with a high density of Hector's and Māui dolphins and high threat intensity; and
2. Relative overlap statistic scaling for population size. This highlighted populations for which the threat intensity is high in the locations that dolphins occur (i.e., where probability of death per dolphin will be high, regardless of the relative abundance of dolphins).

6.4.1.4 RECREATIONAL FISHERIES RISK

Because fisheries observer data are not available for recreational fishing, the impact of recreational set net fishing mortality was estimated on a relative rather than an absolute scale, at the subpopulation level, using the method applied to spatial, non-lethal threats (described above). The full SEFRA approach could not be used for recreational fishing, because there was no means by which to estimate vulnerability to capture. Furthermore, necropsy records attributed to probable and possible bycatch (Table 6.4) comprised an unknown composition of commercial and recreational fishery deaths, precluding the use of the same approach as used for toxoplasmosis and other lethal non-fishery causes of death. This estimation of spatial overlap between dolphins and recreational set net fishing used seasonally resolved (summer/winter) estimates of the relative spatial intensity of recreational netting effort based on two nation-wide fisher surveys (Wynne-Jones et al. 2014, 2019). See section 6.4.4.2, below.

6.4.2 INTRINSIC POPULATION GROWTH (RMAX)

The spatial risk model developed for Hector's and Māui dolphins required a prior distribution of intrinsic population growth rate ($r^{\max}$), the maximum growth rate that will occur at small population size when resources are replete. The $r^{\max}$ affects the Population Sustainability Threshold (PST), reflecting the ability of the species to sustain and recover from impact while meeting a defined population objective.

The risk assessment used individual size at age and maturity stage information to estimate an $r^{\max}$ prior for Hector's dolphins (Edwards et al. 2018). This analysis followed the approach of Dillingham et al. (2016), implemented by Moore (2015), which uses an allometric invariant between optimal generation time (the average age of a breeder during optimal growth) and $r^{\max}$ observed across a wide range of vertebrate species. See Edwards et al. (2018) for a detailed description of methods and sensitivity runs.

The assessment by Edwards et al. (2018) was updated with supplementary ageing and maturity information. This produced a Monte Carlo distribution of $r^{\max}$ with median of 0.050 and 95% credible interval of 0.029–0.071. This empirical estimate replaced a previous base case $r^{\max}$ of 0.018 assumed by the most recent Māui dolphin multi-threat assessment (Currey et al. 2012); the previous estimate was based on an applied maximum longevity of 20 years (Slooten & Ladd 1991), which is now known to be an underestimate for this species (e.g., Gormley 2009).

The revised estimate of $r^{\max}$ for Hector’s dolphin is now consistent with age at first reproduction, given the relationship observed across other mammalian species (Figure 6.6), and is at the low end of the cloud of values defined by other cetacean species (in grey) indicating that at this value of $r^{\max}$ Hector’s dolphins are still among the slowest-reproducing cetaceans relative to their other life history traits, but within plausible bounds.

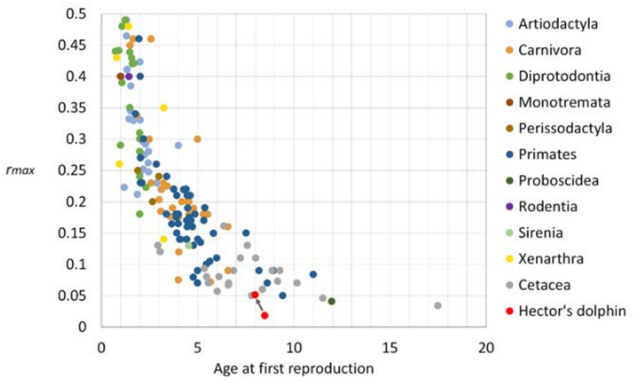


Figure 6.6: Comparative plot of $r^{\max}$ against age at first reproduction for a variety of mammalian orders (Duncan et al. 2007). For Hector’s dolphin, both the previous and updated values are shown (red points). The updated value of $r^{\max}$ derived here for Hector’s dolphin is now consistent with that expected from other mammals, given estimated age at first reproduction. From Edwards et al. (2018).

At very small population sizes (relevant to Māui dolphin), Allee effects may adversely affect realised population growth despite ample resources (and increase the probability of extinction). The mechanisms from which Allee effects arise all impact on individual survival and reproduction and include an array of demographic, genetic, social, and potentially anthropogenic mechanisms. Population simulations were completed using an individual-based model, accounting for demographic stochasticity and inbreeding depression. This produced a mean $r^{\max}$ of approximately 0.045 for a starting population of 50 dolphins (under the latest estimate for Māui dolphins of 63 individuals). The prior used for assessing the population risk of threats to Māui dolphins was adjusted accordingly.

Note that this assessment did not account for catastrophic events or disruption to social systems that might occur at small population size and that would further reduce $r^{\max}$.

6.4.3 COMMERCIAL FISHERY OVERLAP, DEATHS, AND RISK

6.4.3.1 SPATIAL FISHING EFFORT DISTRIBUTIONS

Spatial patterns of inshore set net and inshore trawl fishing effort are shown in Figure 6.7. The risk assessment uses a 3-year average to indicate patterns of ‘current’ fishing effort (i.e., 2014/15–2016/17 fishing years at the time that the risk assessment was run).

In South Island, inshore trawl effort is highest off the ECSI near Timaru. Other locations with concentrated trawl fishing effort also appear in the NCSI in Golden Bay and Tasman Bay and in the SCSI in Te Waewae Bay. Set net fishing effort is most concentrated around Kaikōura Canyon.

For the North Island, set net effort that overlaps the Māui dolphin distribution is most concentrated inside WCNI harbours and near New Plymouth. Inshore trawl effort is highest offshore from Raglan and Kawhia harbours, beyond the limits of the existing 2 nm closure.

6.4.3.2 ESTIMATED VS ACTUAL PATTERNS OF OBSERVED CAPTURES

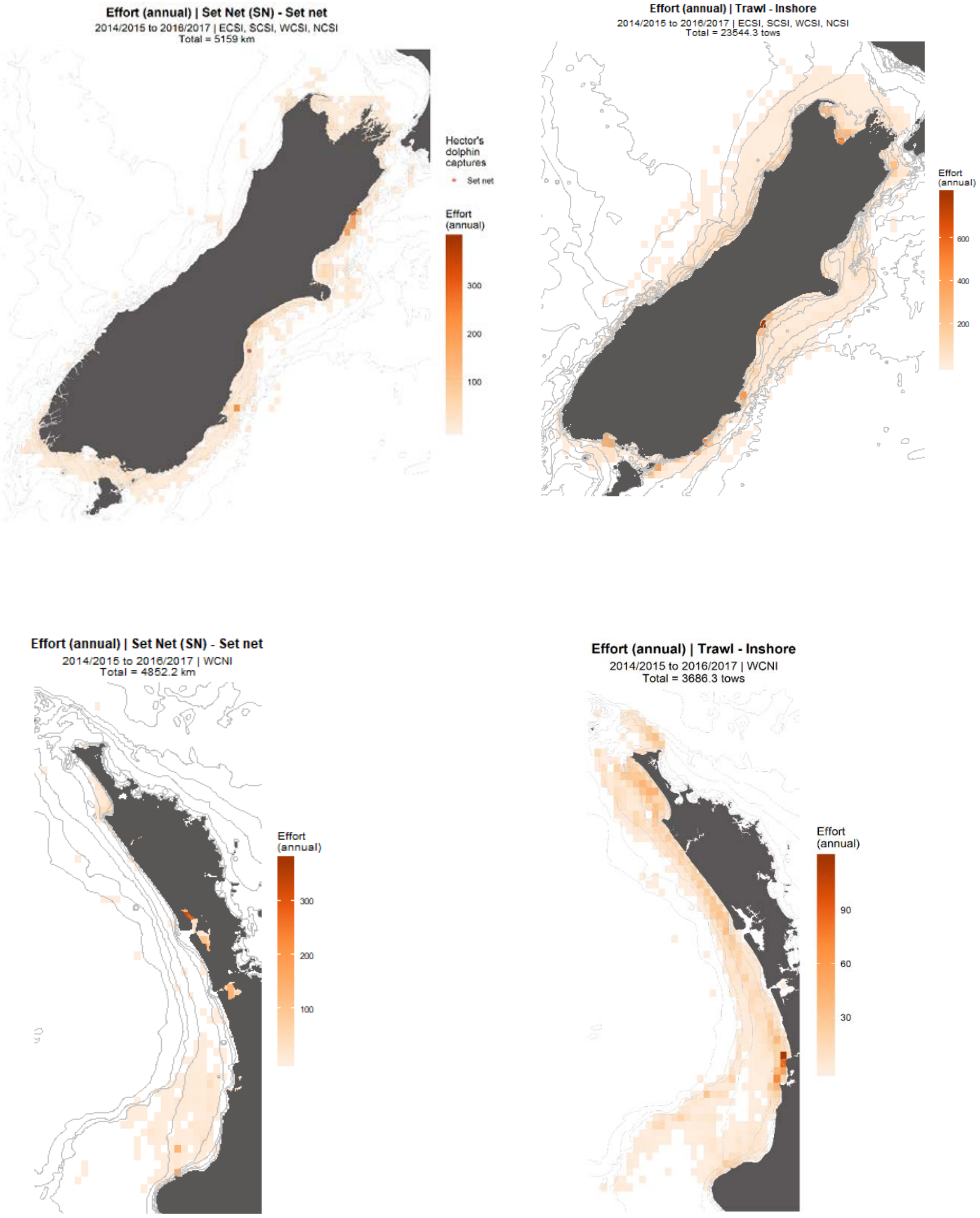
The risk assessment model estimates dolphin captures in space as a function of spatial overlap between dolphins and fishing effort. All observed commercial fishery captures from 1995/96 to 2016/17 were in ECSI set nets, located in areas of high observed overlap near Kaikōura and the Canterbury Bight, which corresponded well with model predictions (Figure 6.8). Good agreement between predicted vs. observed patterns of observed captures indicates that the estimated spatial density of dolphins was a good approximation to the true density, and that vulnerability to capture was relatively constant across inshore set nets operating in different areas. A similar comparison for trawl captures is not meaningful because there has only been a single observed inshore trawl capture.

6.4.3.3 ESTIMATED CAPTURES, DEATHS AND RISK

Commercial set net fisheries were estimated to kill considerably more Hector’s and Māui dolphins than inshore trawl fisheries (Table 6.6), despite considerably higher effort levels and also higher overlap (because existing trawl fishery closures are not as large as set net fishery closures).

This reflects that dolphin catchability is substantially higher in set nets than in trawls: the model estimates that a dolphin is roughly 20–30x more likely to be killed in a set net than in a trawl in any given location.

Figure 6.7: Spatial patterns of commercial fishing effort density (2014/15–2016/17) for inshore set net and inshore trawl fisheries.



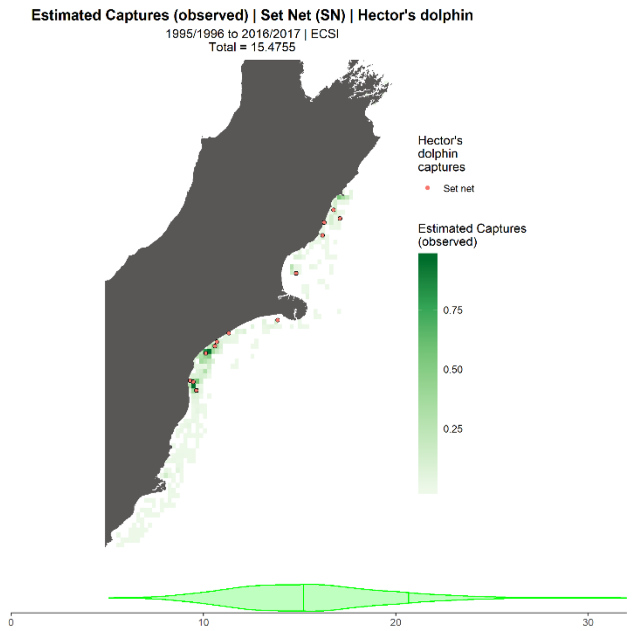


Figure 6.8: Predicted and actual observed Hector's dolphin captures in commercial set nets in the ECSI subpopulation from 1995/96 to 2016/17. The expected pattern of observed captures (as a function of observed spatial overlap) is shown in green; actual observed captures are superimposed in red. The posterior distribution of estimated observed captures is displayed as the violin along the bottom with the median and upper 90% quantile indicated by vertical lines within the violin.

The ECSI subpopulation had the greatest estimated number of annual deaths from both commercial set nets (38.9 individuals per annum, 95% CI = 18.6–88.3) and inshore trawls (3.0 individuals per annum, 95% CI = 0.1–15.6) for the period 2014/15 to 2016/17 (Table 6.6). For the WCSI, the estimated annual deaths are low from both commercial set nets (0.3 individuals per annum, 95% CI = 0.2–0.7) and inshore trawls (1.8 individuals per annum, 95% CI = 0.1–9.4), reflecting low effort.

The estimate of Māui dolphin commercial fisheries deaths was 0.10 deaths per annum (95% CI = 0.0–0.25) in commercial set nets, and 0.02 deaths per annum (95% CI = 0–0.05) in inshore trawl fisheries. No Māui dolphin captures were observed in either fishery from 1995/96 to 2016/17 (or subsequently, to June 2020), with very high observer coverage since 2013 (reflecting Ministerial directives arising from the previous update of the Māui dolphin TMP; MPI & DOC 2012).

For commercial set net fisheries, the median value of the estimated risk ratio was below 1 for all subpopulations. This result suggests that the best estimate of annual mortalities in commercial fisheries did not exceed the PST_{90} between 2014/15 and 2016/17, suggesting that recent commercial fishery mortality levels for set nets in isolation are most likely not sufficiently high to suppress the equilibrium population below 90% of carrying capacity (with over 50% certainty). However the upper 95th percentile of the fisheries deaths estimate did exceed the PST_{90} for all subpopulations except the WCSI, suggesting that it is possible given current uncertainty that fisheries impacts may exceed this level. Risk assessment outputs are typically communicated with reference to both the median and the 90% or 95% confidence level. The level of certainty that decision-makers require that the population objective will be achieved is a policy decision.

Table 6.4: Diagnosed primary cause of death of non-calf Hector's and Māui dolphins by population, from necropsy information for WHAT TIME Period?. Intermediate and full confidence rated diagnoses from Roberts et al. (2019a). ECSI = East Coast South Island, WCSI = West Coast South Island, SCSI = South Coast South Island, WCNI = West Coast North Island.

	Hector's dolphin				Māui dolphin	
Cause of death	ECSI	WCSI	SCSI	WCNI	WCNI	Total
Brucellosis	0	1	0	0	1	2
Deformity	0	0	1	0	0	1
Disease (other)	4	2	0	1	0	7
Miscellaneous	2	2	0	0	1	5
Pneumonia	3	1	0	0	0	4
Predation	0	0	1	0	1	2
Toxoplasmosis	5	2	0	0	2	9
Tuberculosis	1	0	0	0	0	1
Known bycatch	5	0	0	0	0	5
Probable bycatch	4	2	0	0	0	6
Possible bycatch	0	1	0	0	0	1
Unknown/Open	9	3	0	0	0	12
Total	33	14	2	1	5	55

Table 6.5: Necropsy observations used in the estimation of risk from non-fishery threats in the spatial risk model of Roberts et al. (2019a). ECSI = East Coast South Island, WCSI = West Coast South Island, SCSI = South Coast South Island, WCNI = West Coast North Island.

	Hector's dolphin				Māui dolphin	
Cause of death	ECSI	WCSI	SCSI	WCNI	WCNI	Total
Toxoplasmosis	5	2	0	0	2	9
Predation	0	0	1	0	1	2
Other	10	6	1	1	2	20
Total	15	8	2	1	5	31

Table 6.6: Spatial risk model estimates of annual deaths by threat and subpopulation based on data from 2014/15 to 2016/17. This model run assumed that an average of two individuals were killed per inshore trawl capture event. The median and 95% credible intervals are shown.

Cause of death	Subpopulation	50.0%	2.5%	97.5%
Set net	MĀUI	0.10	0.00	0.30
Set net	NI	0.07	0.04	0.17
Set net	TAKA	0.06	0.03	0.13
Set net	NCSI	0.65	0.31	1.47
Set net	WCSI	0.32	0.15	0.74
Set net	ECSI	38.86	18.57	88.25
Set net	SCSI	0.80	0.38	1.81
Inshore trawl	MĀUI	0.00	0.00	0.10
Inshore trawl	NI	0.00	0.00	0.04
Inshore trawl	TAKA	0.00	0.00	0.00
Inshore trawl	NCSI	0.20	0.00	1.08
Inshore trawl	WCSI	3.68	0.16	18.80
Inshore trawl	ECSI	6.08	0.28	31.12
Inshore trawl	SCSI	0.22	0.00	1.12
Toxoplasmosis	MĀUI	1.90	0.96	3.27
Toxoplasmosis	NI	0.25	0.09	0.58
Toxoplasmosis	TAKA	0.40	0.15	0.93
Toxoplasmosis	NCSI	1.10	0.40	2.54
Toxoplasmosis	WCSI	187.03	67.86	432.09
Toxoplasmosis	ECSI	115.06	41.75	265.81
Toxoplasmosis	SCSI	5.05	1.83	11.67
Predation	MĀUI	0.53	0.11	1.42
Predation	NI	0.00	0.00	0.00
Predation	TAKA	0.03	0.01	0.11
Predation	NCSI	0.77	0.16	2.63
Predation	WCSI	62.64	12.72	214.41
Predation	ECSI	17.64	3.58	60.37
Predation	SCSI	2.63	0.53	9.00
Other	MĀUI	4.06	2.65	5.99
Other	NI	0.42	0.17	0.88
Other	TAKA	0.56	0.23	1.16
Other	NCSI	9.06	3.69	18.78
Other	WCSI	232.05	94.49	480.99
Other	ECSI	411.79	167.67	853.54
Other	SCSI	14.05	5.72	29.13

6.4.3.4 ADJUSTING FOR MULTIPLE-CAPTURE TRAWL EVENTS

Fisheries observers have only recorded a single Hector's dolphin capture in inshore trawl fisheries. In contrast, there have been 13 inshore trawl events in which Hector's dolphin captures were reported by fishers. Following two fisher-reported multiple capture events in early 2019 in which three individuals were reported captured on a single trawl, the AEWG judged that observed captures (Table 6.2) were indicative of the likelihood of a capture event, but that the number of animals captured per event may be more accurately reflected in the frequency of multiple-capture events reported by fishers. In 13 such events, six captured between 2 and 4 individuals; in total 25 animals were captured (i.e., 1.92 individuals per positive capture event). Assuming that on average two individuals are captured per inshore trawl capture event, this would lead to a doubling of the estimated annual deaths and risk from the risk model (values shown in Table 6.6). These double trawl risk values are shown as a sensitivity in appendix 17 of Roberts et al. (2019a); on the advice of the AEWG these are the trawl risk numbers that were used to inform the update of the Hector's and Māui dolphin TMP.

6.4.3.5 CHANGE IN FISHERIES RISK OVER TIME

Figure 6.9 illustrates temporal trends in commercial set net fishing effort and spatial overlap per unit effort, and resulting estimates of fisheries deaths and risk over time at the subpopulation scale (Māui dolphins and Hector's dolphins). For Hector's dolphins, estimated trawl risk has declined steadily since 1992/93 due to reduced effort, but in the commercial set net fishery an overall reduction in effort has been offset by a general increase in overlap per unit effort resulting in little change in risk through time (Figure 6.9). This result was counterintuitive given the establishment of spatial set net closures in 2008, but the spatial risk model suggests that in places where Hector's dolphins are abundant, their distribution extends well beyond these closures into areas where set net fishing is ongoing. Nonetheless the median estimate of risk ratio was below 1 in all years since 1992/93, indicating that (in the absence of other anthropogenic mortality) the estimated annual mortalities across the last 25 years are unlikely to have been sufficient to prevent population recovery to or stabilisation at levels above at least 90% of carrying capacity.

For Māui dolphins, the estimated annual set net deaths and risk ratios have declined steadily since 1992/93, due to decreasing total effort and reduced spatial overlap per unit effort, reflecting previous spatial fishery closures. Trawl fishery estimates show similar trends.

6.4.3.6 SPATIAL PATTERNS OF FISHERIES RISK

Spatial distributions of model estimated fisheries deaths are shown in Figure 6.10. The spatial patterns of captures, deaths, and risk are the same because all are proportional to spatial overlap.

In the South Island the spatial risk model predicts that set net deaths will occur mostly in Pegasus Bay north of Banks Peninsula where there are large numbers of dolphins in locations further offshore than the existing fisheries closures, and also in Kaikōura, where dolphin numbers are moderate to low, but fishing effort is highly concentrated. The model predicts that trawl fishery deaths will be highest near Timaru, where dolphins are abundant and fishing effort is high.

In the North Island the spatial risk model predicts that set net captures are most likely in low dolphin density locations, because set net fishing has already been eliminated from areas with high dolphin densities. Captures are predicted to be most likely in WCNI harbours, due to very high fishing effort (note however that the structural assumptions underlying this prediction are untested). The model also predicts captures in low dolphin-density locations near New Plymouth, for similar reasons (but in this instance model predictions of low but non-zero dolphin presence are supported by sightings data). The model predicts that trawl captures are most likely to occur near Raglan and Kawhia harbours, where the estimated dolphin distribution extends beyond the existing 2 nm trawl closure.

Using the risk spatial risk model described by Roberts et al. (2019a) and a customised query interface ('Risk Atlas'; D Webber unpublished), in 2019 spatial risk estimate outputs analogous to Figures 6.9 and 6.10 were used at the smaller scales of subpopulations and local populations, and within user-defined boundaries simulating the effects of various spatial fishery closures, to evaluate alternate fisheries risk reduction options under an updated Threat Management Plan. These options are currently (June 2020) under consideration.

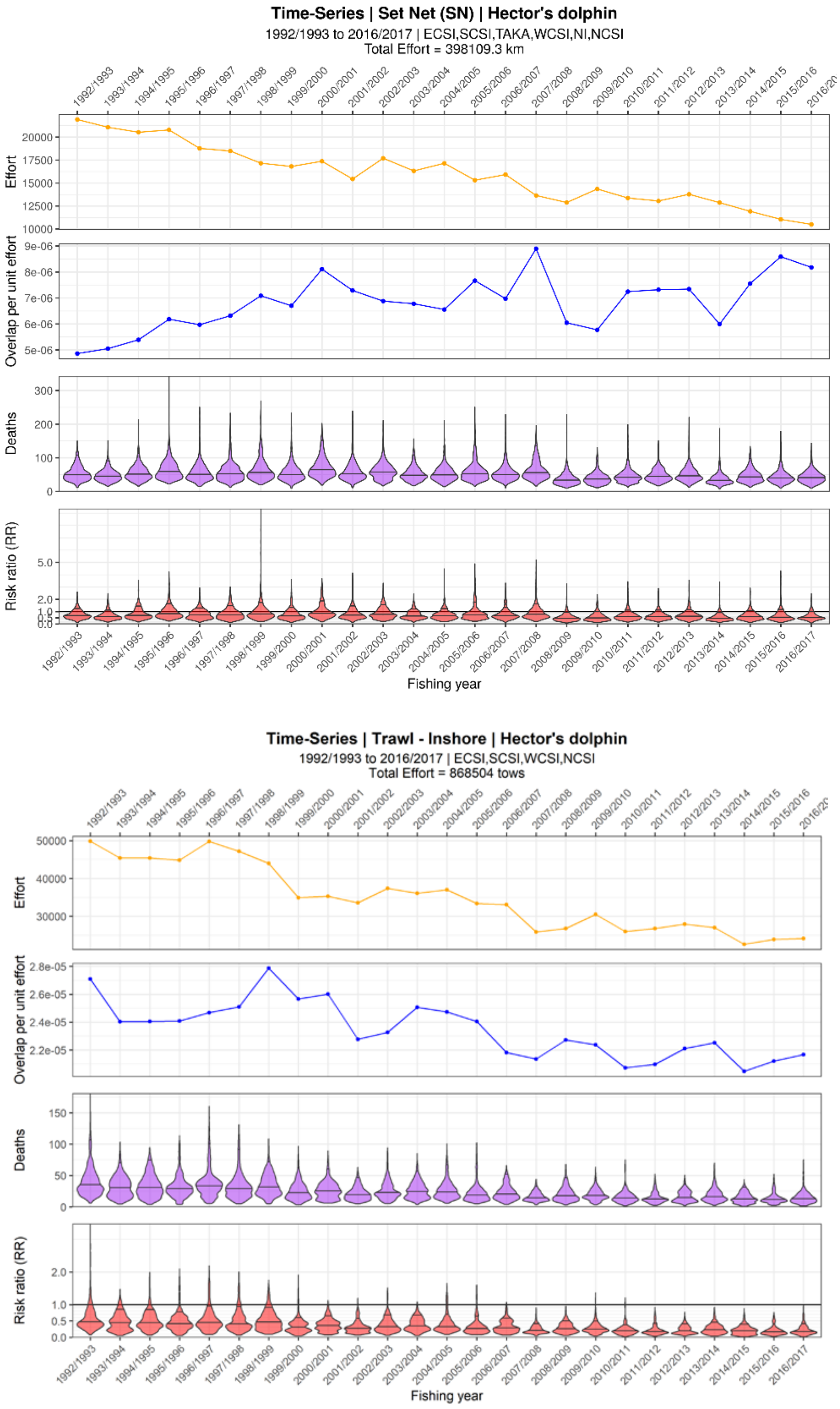
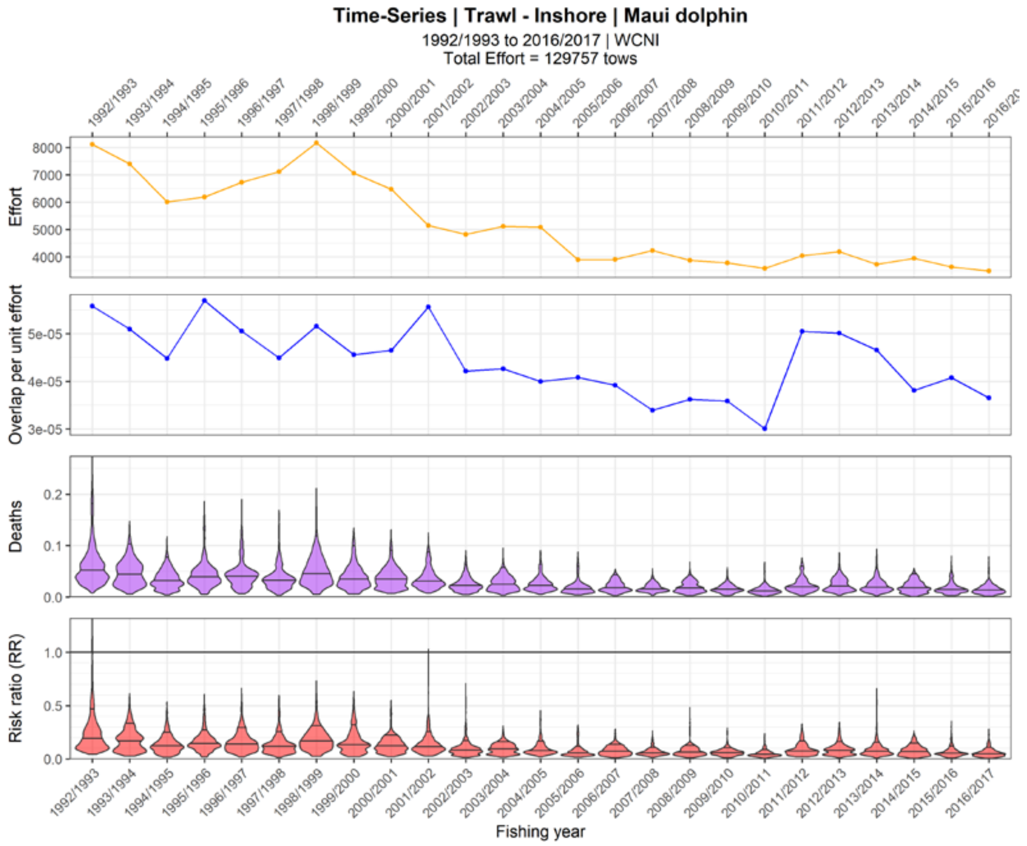
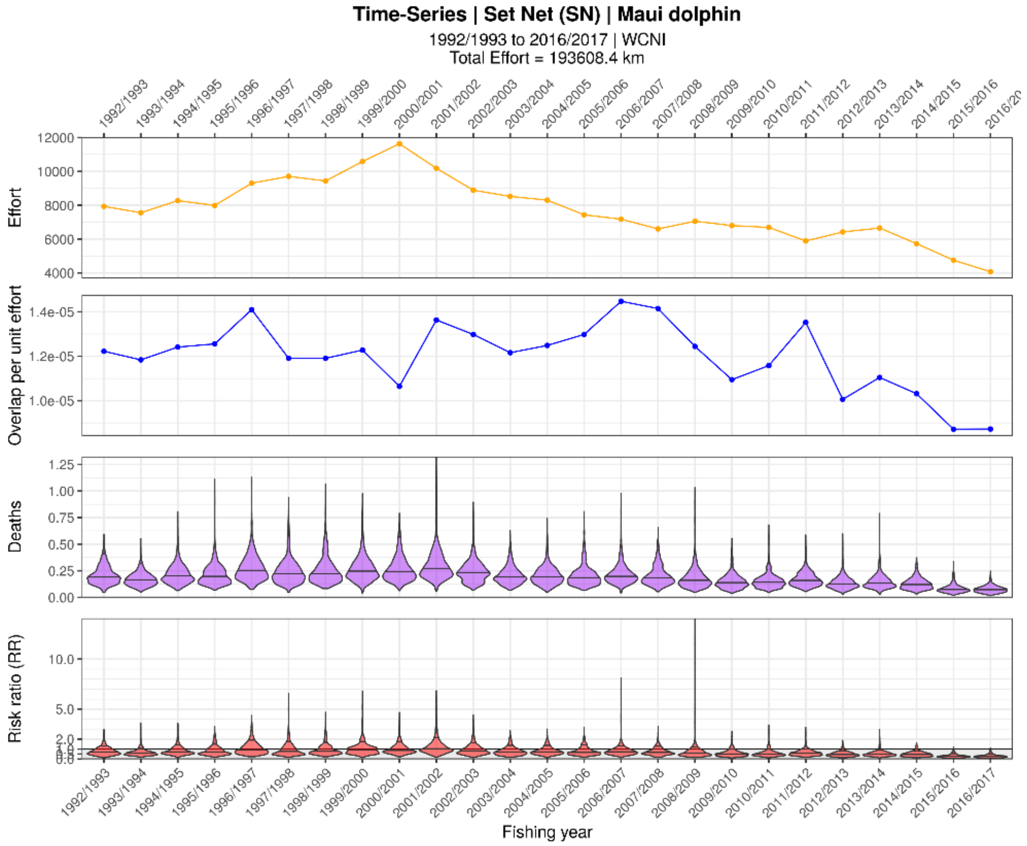


Figure 6.9: Change in estimated fisheries deaths and risk to Hector's dolphins over time arising from changes in effort and spatial overlap, for set net (upper) and inshore trawl (lower). Note that trawl deaths depicted here reflect the x2 sensitivity whereby on average two animals are killed per capture event. Risk score outputs in this model run applied a calibration coefficient (ϕ) of 0.2. [Continued over the page]


Time-Series | Trawl - Inshore | Maui dolphin

1992/1993 to 2016/2017 | WCNI

Total Effort = 129757 tows


Time-Series | Set Net (SN) | Maui dolphin

1992/1993 to 2016/2017 | WCNI

Total Effort = 193608.4 km

Figure 6.9: Change in estimated fisheries deaths and risk to Māui dolphins over time arising from changes in effort and spatial overlap, for set net (upper) and inshore trawl (lower). Note that trawl deaths depicted here reflect the x2 sensitivity whereby on average two animals are killed per capture event. Risk score outputs in this model run applied a calibration coefficient (ϕ) of 0.2.

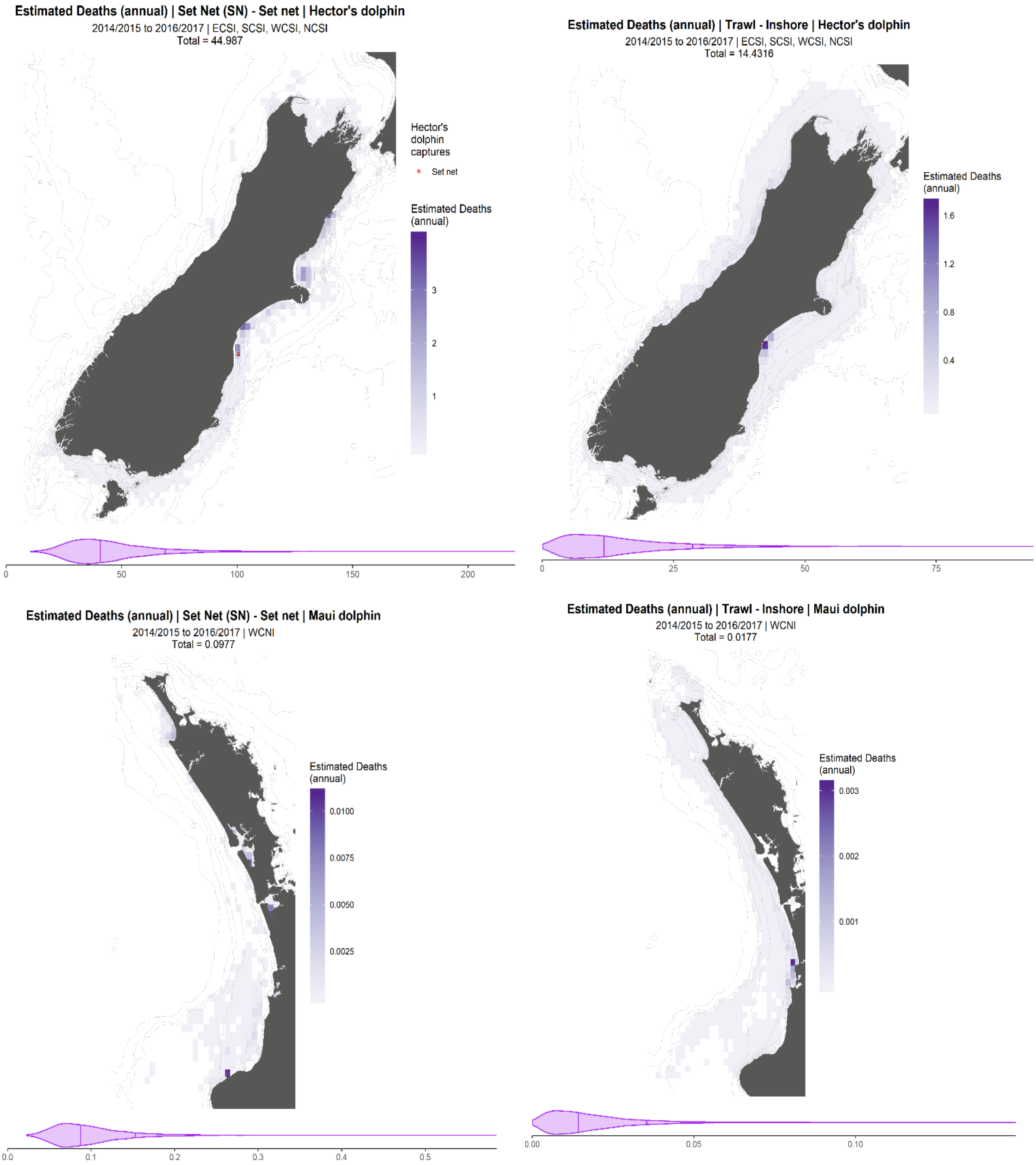


Figure 6.10: Spatial patterns of estimated annual fisheries deaths (hence also capture and risk) for Hector's dolphins (upper) and Māui dolphins (lower) from 2014/15 to 2016/17. Violin plots below each map depict the model posterior estimates of deaths; median and 90th percentile estimates are marked by vertical lines. Note that trawl deaths depicted here reflect the x2 sensitivity whereby on average two animals are killed per capture event.

6.4.3.7 FACTORS AFFECTING STATISTICAL UNCERTAINTY IN FISHERIES RISK

The wide model posteriors of commercial set net fishery deaths and risk ratios estimates primarily stem from vague priors with respect to the cryptic mortality multiplier (reflecting bodies that may drop out of the net without being observable). In contrast, the posterior for set net catchability was well estimated despite an uninformed prior, indicating that existing set net observer data are sufficient to inform relatively precise total captures estimates. For this reason increased observer coverage would lead to a relatively minor improvement in the precision of set net risk ratio estimates.

In contrast, in trawl fisheries cryptic mortality has far less influence, but trawl catchability is less well estimated, reflecting that there has only been a single observed trawl fishery capture. In locations where dolphins are abundant, increased observer coverage or electronic monitoring of trawl fishing effort can be expected to yield improved precision in the estimation of trawl fisheries risk.

Note that because the estimation of dolphin catchability in the spatial risk assessment uses only the data from observed fishing events, for which geographical locations are recorded by the fisheries observer, this part of estimation of fisheries risk is not subject to potential bias arising from non-representative fisheries observer coverage or imprecise position reporting. However where the catchability estimate is then applied to estimate total deaths across the fishery including in un-observed fishing events, these estimates will be affected by the accuracy with which fishing effort locations are recorded.

In the spatial risk assessment by Roberts et al. (2019a), all fishing effort locations representative of 'current' commercial fisheries risk (in Figure 6.7) are recorded precisely (with the exception of small vessel set net fisheries operating inside WCNI harbours, for which locations were estimated using data from a cellphone tracking app; see Roberts et al. 2019a). Hence the estimates of current fisheries risk (shown in Figures 6.10 and 6.13, and Table 6.6) will not be affected by bias arising from spatial effort reporting imprecision. However, inshore trawl fishing effort locations have only been recorded precisely since the introduction of new reporting forms in 2006 and 2007; fishing effort in earlier years was reported to fisheries statistical areas, and the actual position estimated subsequently. For this reason the year-specific estimates from the 1990s and mid-2000s (as in the annual time series in Figure 6.9, below) may be subject to greater uncertainty than is shown.

6.4.3.8 RISK ASSESSMENT OUTPUTS COMPARED WITH PRE-EXISTING ESTIMATES OF COMMERCIAL FISHERIES CAPTURES

Prior to 2012, the only observer programme with sufficient coverage to yield a robust estimate of the rate of incidental capture of Hector's dolphins in inshore commercial set nets (Baird & Bradford 2000) was an observer programme in Statistical Areas 018, 020, and 022 (FMA 3) on the east coast of the South Island in the 1997/98 fishing year, which observed 214 inshore set net events, targeting shark species and elephant fish. Eight Hector's dolphins were caught in five sets, of which two were released alive. Capture rates were most precise in Area 022, where six of the catches were reported, following observer coverage of 39% (Baird & Bradford 2000). Capture rate was estimated at 0.064 dolphins per set (CV = 43%) in Area 022 and 0.037 dolphins per set (CV = 39%) in Areas 020 and 022 combined (Baird & Bradford 2000). A total of 16 dolphins (CV = 43%) were estimated to have been captured in Area 022, and 18 dolphins (CV = 38%)[16] dolphins captured in Areas 020 and 022 combined (noting these are captures not deaths, i.e. not including cryptic mortality) (Baird & Bradford 2000). These estimates are from Statistical Areas containing the Banks Peninsula Marine Mammal Sanctuary (BPMMS), which at that time effectively prohibited commercial set netting between Sumner Head and the Rakaia River out to 4 nm from the coast (Dawson & Slooten 1993).

Using Risk Atlas, the risk assessment outputs by Roberts et al. (2019a) can be queried within user-defined boundaries, including estimates for previous fishing years. An extract performed to replicate the boundary conditions of Baird &

---

[16] This was reported as either 16 or 18 dolphins in the cited reference, but has been confirmed as 18 dolphins by correspondence with the author (S. Baird, pers. comm.).

Bradford (2000), i.e., estimating set net risk within Statistical Areas 020 and 022 in the 1997/98 fishing year – yielded a mean estimate of 16.4 set net captures (or 30.7 deaths (90% c.i. 14.1–54.8) including cryptic mortality). This is very similar to the Baird and Bradford (2000) estimate of 18 captures (CV = 38%), which did not include cryptic mortality.

Slooten & Davies (2012) used the observed set net data from 2009/10 to estimate total captures on the ECSI of 23 dolphins (CV = 0.21). This was the first published capture estimate since extensive protection measures to mitigate Hector's dolphin risk were introduced in 2008.

An extract from the model of Roberts et al. (2019a), performed to replicate the boundary conditions of Slooten & Davies (2012), yielded a mean estimate of 23.0 set net captures (or 43.0 deaths (90% c.i. 23.9–74.3) including cryptic mortality). This is very similar to the Slooten & Davies (2012) estimate of 23 captures (CV = 0.21), which did not include cryptic mortality.

To inform the update of the Māui dolphin TMP in 2012, an expert panel identified 23 threats potentially relevant to Māui dolphins. For those threats that could be mapped spatially, the spatial distribution of the resulting impact was estimated by calculating the spatial overlap between the threat and the spatial density of the dolphins. In the absence of any empirical means of estimating the number of dolphin deaths attributable to each threat, these were estimated qualitatively via structured expert elicitation (Currey et al. 2012). The expert panel workshop judged that, in decreasing order of magnitude, the most important threats to Māui dolphins were: commercial set nets (2.3 deaths per year); commercial trawls (1.1 deaths per year); recreational set nets (0.9 deaths per year); mining and oil activities (0.1 equivalent deaths per year); vessel traffic (0.07 deaths or equivalent deaths per year); pollution (0.05 deaths or equivalent deaths per year); and disease < 0.01 deaths or equivalent deaths per year).

Notably, the expert panel estimates do not resemble the model estimate fitted to necropsy data (Roberts et al. 2019a), e.g., as in Table 6.6. The most notable omission is that disease was not recognised as a significant threat among the assembled experts by Currey et al. (2012). It was only subsequently that Roe et al. (2013) published the result that 2 of 3 Māui dolphins necropsied and tested in the period 2007–2011 had died as a result of *Toxoplasma gondii* infection, suggesting that the expert panel may have underestimated mortality from this source. Currey et al. (2012) reported that toxoplasmosis was not among the threats considered by the expert panel because this information was not available at the time of the risk assessment workshop. Instead the assembled experts estimated that 95% percent of annual deaths were likely to be attributable to commercial or recreational fisheries.

6.4.4 NON-COMMERCIAL FISHERY THREATS

6.4.4.1 TOXOPLASMOSIS, PREDATION, AND OTHER LETHAL NON-FISHERY THREATS

Updated necropsy observations used to inform the estimation of non-fishery deaths are given in Table 6. and 6.5. Toxoplasmosis was the primary cause of death other than entanglement in fisheries gear that was considered to have an anthropogenic origin. Toxoplasmosis was first identified as a major non-fishery threat for both Hector's and Māui dolphins towards the end of the 2012 TMP risk assessment process (Roe et al. 2013). Prior information suggests that toxoplasmosis mortalities affect both Hector's and Māui dolphins, and toxoplasmosis mortalities are geographically widespread around the South Island (Roe et al. 2013). The spatial risk assessment estimated the summer and winter relative densities of *T. gondii* oocytes in coastal waters (Figure 6.11) as a function of the estimated distribution of cats around New Zealand and rainfall or run-off using an existing hydrology model (see appendix 9 of Roberts et al. 2019a). Spatial overlap between toxoplasma exposure densities and the spatial abundance of Hector's and Māui dolphins were then used to estimate relative risk levels to different subpopulations in the spatial risk model.

Estimates of cause of death arising from the necropsy observations fitted to the spatial risk model are shown in Table 6.. For the purposes of model fitting, the total for each cause of death were used (across all sub-areas). Of the 31 non-calf dolphins for which a primary cause of death could be determined and that were not attributed to bycatch mortality, 9 deaths were attributed to toxoplasmosis, 2 were attributed to predation, and the remainder were attributed to "other" non-fishery causes of death (mostly constituting 'natural mortality'). The sample size of observations by sub-area were small, with the bulk of sample coming from the ECSI (15) or WCSI (8), with a similar composition of causes of death in these two areas. Model estimated annual deaths from toxoplasmosis were greater than those from commercial fisheries for all subpopulations (Table 6.6 and Figure 6.10). This was the case for the model run assuming an equal detection probability of non-fishery causes of death and also for the predation sensitivity model run, which assumed a 10-fold reduction in the detection probability of predation deaths (hence 10x more predation deaths occurring). Note however that because exposure to both toxoplasmosis and shark predation vary substantially in different locations, the relative importance of different threats or natural causes of death at the scale of particular subpopulations may be more sensitive to assumptions about predation detectability than are conclusions at the scale of the entire species. The highest number of annual toxoplasmosis deaths was estimated for the WCSI population (187.0 individuals per annum, 95% CI = 67.9–432.1); this estimate was lower for the predation sensitivity (106.8 individuals per annum, 95% CI = 32.7–284.4) under which predation was responsible for a corresponding increased proportion of non-fishery deaths.

Figure 6.11: Estimated relative coastal water density of *Toxoplasma gondii* oocysts in winter (red = high density, blue = low density). From Roberts et al. (2019a).

For the WCNI where Māui dolphins occur (labelled “MĀUI” in Table 6.6), the estimated annual deaths from toxoplasmosis (1.9 individuals per annum, 95% CI = 1.0–3.0) were much higher than from either commercial set nets (0.10 individuals per annum, 95% CI = 0.0–0.25) or the inshore trawl fishery (0.02 individuals per annum, 95% CI = 0.0–0.05). The relatively high toxoplasmosis risk ratio for Māui dolphins reflects very high estimates of *T. gondii* oocyst densities around the North Island, particularly in winter months, in the area south of Manukau Harbour (Figure 6.11). The Waikato River in particular drains a very large catchment with high domestic and feral cat densities. The core of the Māui dolphin range is largely confined to the area of freshwater influence from this and other WCNI rivers (Hunt & Jones 2020).

Note that uncertainty arising from low sample size in the necropsy data is reflected in the wide confidence intervals around estimates of toxoplasmosis deaths (although for Māui dolphins, even the lower bound of this statistical uncertainty exceeds the upper bound of the estimated commercial fishery deaths). Furthermore the comparability of estimates of commercial fishery deaths and non-fishery deaths, e.g., from toxoplasmosis, will potentially be affected by biases associated with using a necropsy sample primarily obtained from beach-cast individuals. Potential sources of bias include threat-specific differences in the timing and location of death which may affect the relative likelihood of carcass recovery for necropsy. To illustrate, deaths that occur in summer are more likely to be reported by beachgoers, so may be over-represented in necropsy results. All nine confirmed toxoplasmosis mortalities to date were recovered in the period from September to November (Roe et al. 2013; DOC 2020a).

6.4.4.2 RECREATIONAL FISHERIES RISK

The relative spatial threat posed by recreational set netting to Hector’s and Māui dolphin subpopulations was estimated based on relative spatial overlap. The locations of reported recreational set net fishing events were compiled from the results of two nationwide recreational fishing panel surveys (Wynne-Jones et al. 2014, 2019) and manually assigned to named locations by Fisheries New Zealand fisheries managers familiar with the operation of these fisheries. Note that survey answers did not distinguish between recreational set net, dragnet and throw-net fishing effort; of these only set nets are thought to pose a risk to dolphins. During data compilation, obvious throw-net and drag-net effort was excluded, but it is likely that the conflation of these three effort types nonetheless creates additional noise within the data.

Locations around the North Island with the highest recreational set net effort included the Hauraki Gulf and the area from the Kāpiti Coast northward to Wanganui. High recreational effort locations around the South Island included Golden Bay and Tasman Bay, and to a much lesser extent Banks Peninsula and the coastline adjacent to Invercargill. The spatial distribution of recreational effort used in the risk assessment is shown in figure A12 of Roberts et al. (2019a).

For all subpopulations, recreational fisheries overlap was estimated to be much higher in the summer period (Table 6.7). When scaled for population size, the highest overlap (and hence the highest estimated encounter rate per dolphin with recreational netting events) was estimated for the 'Taranaki to Kāpiti' (TAKA) sub-area. Despite the absence of evidence of a resident dolphin population here, these results indicate that any dolphin transiting this area is more than three times as likely to encounter recreational set net effort relative to dolphins in any established subpopulation. The second highest relative risk was estimated for the NCSI population (Golden Bay and Tasman Bay); the lowest levels were estimated for the large Hector's dolphin populations of the ECSI and WCSI (Table 6.7), reflecting historical fishery closures in 2008 that substantially reduced opportunities for recreational set netting. The recreational set netting that remains in these areas is confined to harbours and subject to seasonal restrictions.

Potential risks to dolphins arising from illegal set net fishing was also discussed. Spatial patterns of illegal set net behaviour effort are inherently difficult to estimate, but it is likely that where recreational set netting is uniformly banned over large areas then illegal fishing behaviour will also diminish, because uniform regulations become easier to enforce.

6.4.4.3 NON-LETHAL OR HABITAT-DISRUPTIVE THREATS

With respect to aquaculture facilities, regions of relatively high spatial overlap were limited to a small number of farms off the ECSI (Pegasus Bay and Cloudy Bay) and NCSI (Golden Bay and Tasman Bay). When scaling for population size, the highest overlap (i.e., highest likelihood of encounter per dolphin) was estimated for the NCSI subpopulation, However, the spatial extent of this overlap was small (Table 6.7).

Spatial oil spill risk is relatively high on the north coast of the North Island, in Cook Strait, and off northern Banks Peninsula. Of these locations, only northern Banks Peninsula has a high estimated density of Hector's dolphins, and so this location has the greatest threat to dolphins in terms of number of dolphins that might be affected (if oil spill events are consistent with the estimated spatial threat intensity). When scaling for population size, the ECSI had the greatest overlap with oil spill risk (Table 6.7).

The spatial cumulative underwater noise from vessel traffic (using AIS data) and selected oil and gas seismic surveys were estimated for the region to the west of the North Island from noise modelling by McPherson et al. (2019) (Figure 6.12). This modelling was supplemented by a review of the potential impacts of petroleum and mineral exploration and production on Hector's and Māui dolphins by Lucke et al. (2019), which illustrated the spatial distribution of seismic surveys around New Zealand since 1960. The most intensive historical activity was to the west of the North Island, including survey activity prior to 2010 in regions that would overlap with regions of moderately high Hector's and Māui dolphins (although not since 2010).

Lucke et al. (2019) concluded that seismic surveys and offshore pile driving pose the greatest risk for auditory impairment, but that the risk from lower frequencies primarily emitted by seismic testing is lower if the probable frequency-specific sensitivity of Hector's dolphin is considered (i.e., because these dolphins have a high-frequency auditory and vocalisation range; note however that cetaceans often respond to sounds outside the frequency range of their own vocalisations). Behavioural reactions (i.e., spatial avoidance) were considered the most probable responses to the assessed noise sources and expected sound exposure levels, but scientifically-robust data are lacking for assessing the behavioural responses of Hector's and Māui dolphins to sound. Elsewhere Leunissen & Dawson (2018) and Leunissen et al. (2019) document behavioural responses to pile driving / construction noise in the inshore environment, showing that spatial displacement can occur.

Table 6.7: Relative overlap between threats and Hector's/Māui dolphins by threat, subpopulation and season. Rescaled as a proportion of the maximum value for a respective threat across all subpopulations and both seasons. ECSI = East Coast South Island, SCSI = South Coast South Island, WCNI = West Coast North Island, TAKA = South Taranaki and Kāpiti Coast, WCSI = West Coast South Island, NI = All other coasts of the North Island, NCSI = North Coast South Island.

Subpopulation	Toxoplasmosis	Predation	Recreational netting	Oil spill risk	Aquaculture
Summer					
ECSI	0.15	0.16	0.04	0.95	0.12
SCSI	0.19	0.69	0.21	0.36	0.02
WCNI	0.20	0.23	0.16	0.08	0.00
TAKA	0.24	0.20	1.00	0.30	0.00
WCSI	0.48	1.00	0.02	0.01	0.00
NI	0.14	0.01	0.41	0.77	0.20
NCSI	0.06	0.29	0.29	0.19	1.00
Winter					
ECSI	0.26	0.15	0.01	1.00	0.17
SCSI	0.34	0.68	0.02	0.38	0.01
WCNI	1.00	0.20	0.02	0.10	0.00
TAKA	0.82	0.22	0.09	0.34	0.00
WCSI	0.71	0.98	0.01	0.01	0.00
NI	0.73	0.01	0.05	0.67	0.20
NCSI	0.12	0.33	0.05	0.18	0.80

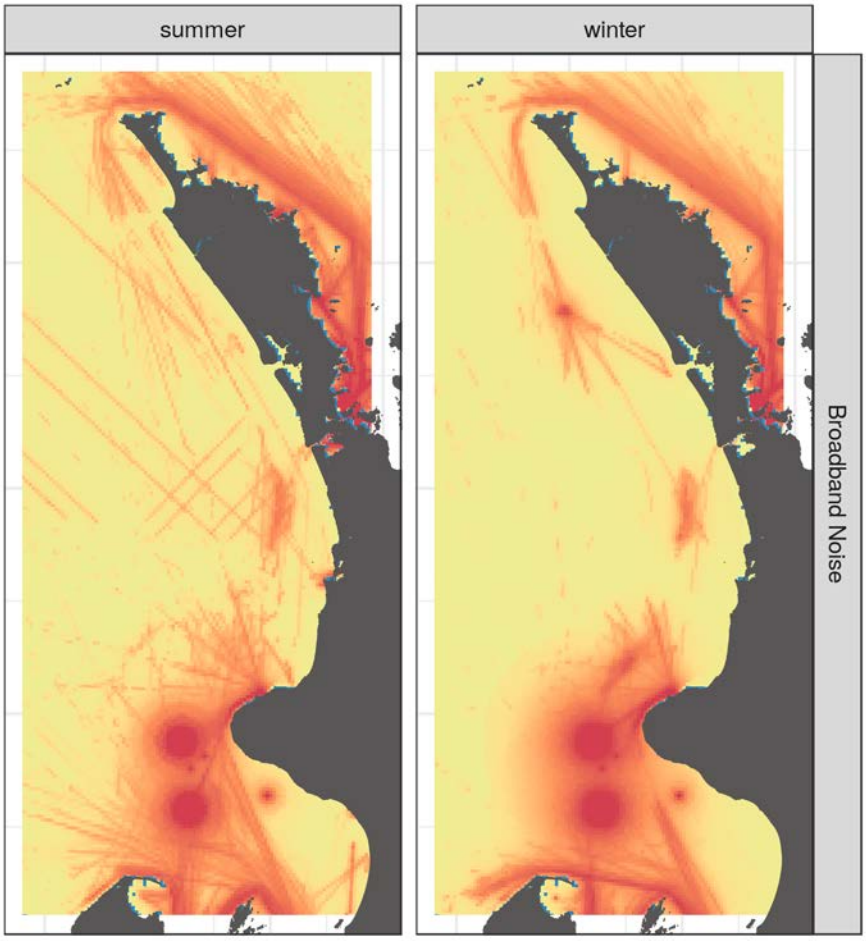


Figure 6.12: Estimated cumulative high-frequency noise in summer (left) and winter (right). Spatial estimates from noise modelling by McPherson et al. (2019).

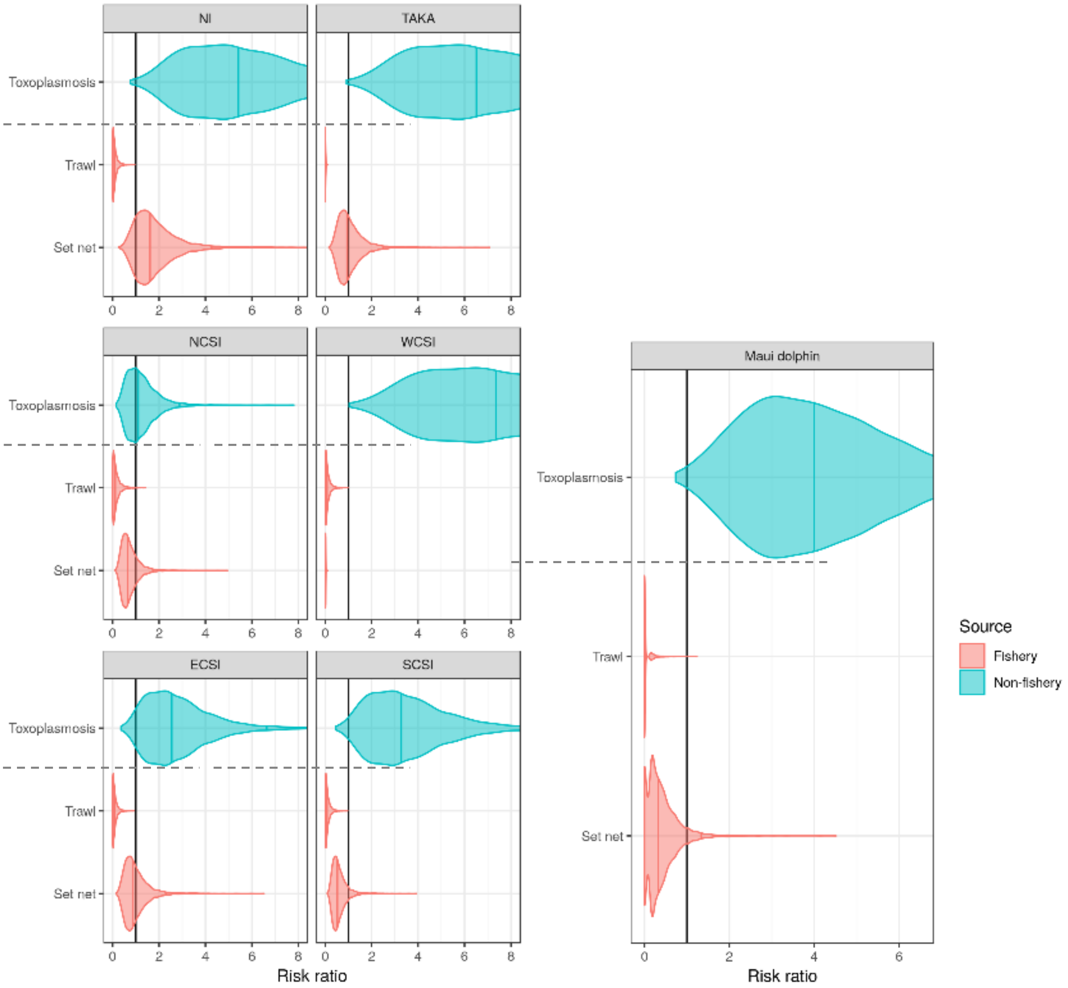


Figure 6.13: Annual commercial fishery (set net and inshore trawl) and toxoplasmosis risk ratios for Hector's dolphins by subpopulation area, under the base case (equal detection probability) scenario for non-fishery causes of death. The median and 97.5% quantile are indicated as vertical lines within each density. Dashed lines delineate threats for which differing methods were used to estimate annual risk ratio (above the line = based on proportions in the necropsied sample; below the line = using fisheries observer data). Reproduced from Roberts et al. (2019a).

6.5 HECTOR'S AND MĀUI DOLPHIN DEMOGRAPHIC POPULATION MODELS

In 2018–19 Fisheries New Zealand commissioned two separate demographic population assessments for Māui dolphins, to inform the revised TMP for Hector's and Māui dolphins.

6.5.1 POPULATION-BASED MODELS

A Bayesian population model described by Roberts et al. (2019b) was developed for Māui dolphins using the SeaBird demographic software (e.g., Roberts & Doonan 2016) integrating information from genetic "mark-recapture" observations and a population size time series, also from genetic biopsy (e.g., Baker et al. 2016b). Model runs made alternative assumptions of historical threat-specific mortality from direct fishery interactions (set net and trawl) and toxoplasmosis, as estimated by the spatial risk assessment of Roberts et al. (2019a). Models estimated a higher median annual non-calf (1+) survival probability for females (~0.89) than for males (~0.83), consistent with other assessments using the same data (e.g., Cooke et al. 2019).

Because current annual commercial fishery deaths are estimated to be low relative to other causes of death, model projections estimated only a minor effect of alleviating estimated trawl and set net mortalities, even when the upper 95% credible interval estimate of annual deaths (from the spatial risk assessment) was assumed. Where adult survival was estimated in a single time block (i.e., assuming constant 'background' mortality with only the fisheries deaths changing), this effect was insufficient to stabilise or reverse a declining population trend. In contrast, model runs alleviating toxoplasmosis deaths and commercial fishery deaths simultaneously produced increasing or stable population trends, depending on the detection probability of toxoplasmosis deaths relative to predation events (Figure 6.14)

6.5.2 INDIVIDUAL-BASED MODELS

Cooke et al. (2018) fitted an individual-based model to a time series of genetic mark-recapture data (Baker et al. 2013, 2016b) to estimate survival and other demographic rates. Cooke et al. (2019) modified this model to incorporate (from the spatial risk assessment by Roberts et al. 2019a) priors for biological parameters and for empirical estimates of time-varying annual commercial fisheries exploitation rates. Cooke et al. (2019) then used this model to simulate forward population trajectories for Māui dolphins under four sets of structural assumptions, as follows:

a) commercial fisheries deaths estimated by the spatial risk assessment are accurate in an absolute sense, there are no other anthropogenic deaths. These model runs did not fit the observed population trend.

b) commercial fisheries deaths estimated by the spatial risk assessment are accurate as a relative index only; there are no other anthropogenic deaths. These model runs fit the observed population trend but required that the catchability of Māui dolphins per encounter with fishing effort is roughly 10–20x higher than was estimated empirically for Hector's dolphins. Such a dramatic difference in inherent characteristics between subpopulations is considered implausible.

c) Commercial fisheries deaths estimated by the spatial risk assessment are accurate, and there are other (unspecified) anthropogenic causes of death that are constant over time. These runs estimate that 2.9–4.3 excess deaths per year are required to best fit the observed population trend.

d) commercial fisheries deaths estimated by the spatial risk assessment are accurate, and toxoplasmosis is also present, at levels estimated in the model based on WCNI necropsy results. These runs suggest that toxoplasmosis is responsible for 2.8–4.1 deaths per year, comparable to all excess deaths required to best fit the observed trend under group c) above.

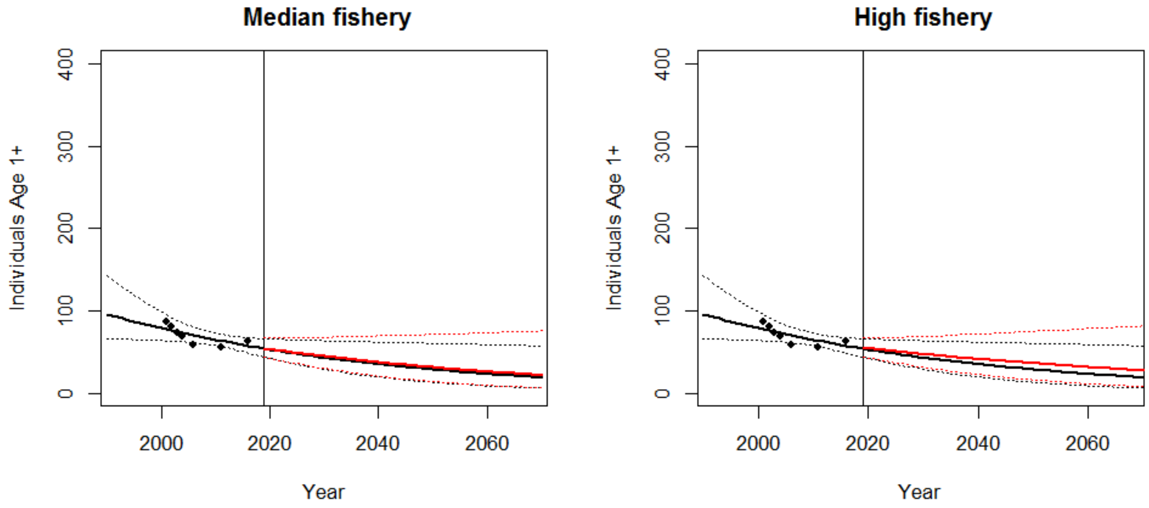


Figure 6.14: Māui dolphin population projections with alternative assumptions with respect to alleviating future threat-specific annual deaths (from Roberts et al. 2019b). Current year (2019) is highlighted by vertical line. To the left of this line: black lines are the median and 95% CI of MCMC estimates of non–calf population trajectory; and census estimates are indicated by black points. To the right of the vertical line: black lines are the projected population trajectory for a model continuing recent demographic rates. Projections *alleviating* threat-specific mortality are shown in red: median estimates of annual set net and trawl deaths (top left); the upper 95% estimates of annual set net and trawl deaths (top right); the median fishery deaths and toxoplasmosis, assuming equal detection probability of non–fishery causes of death (bottom right); and the median fishery deaths toxoplasmosis, assuming 10–fold decrease in detection probability of predation mortality (bottom left). For all trajectories, the three lines represent median and 95% CI of MCMC estimates. (Continued next page)

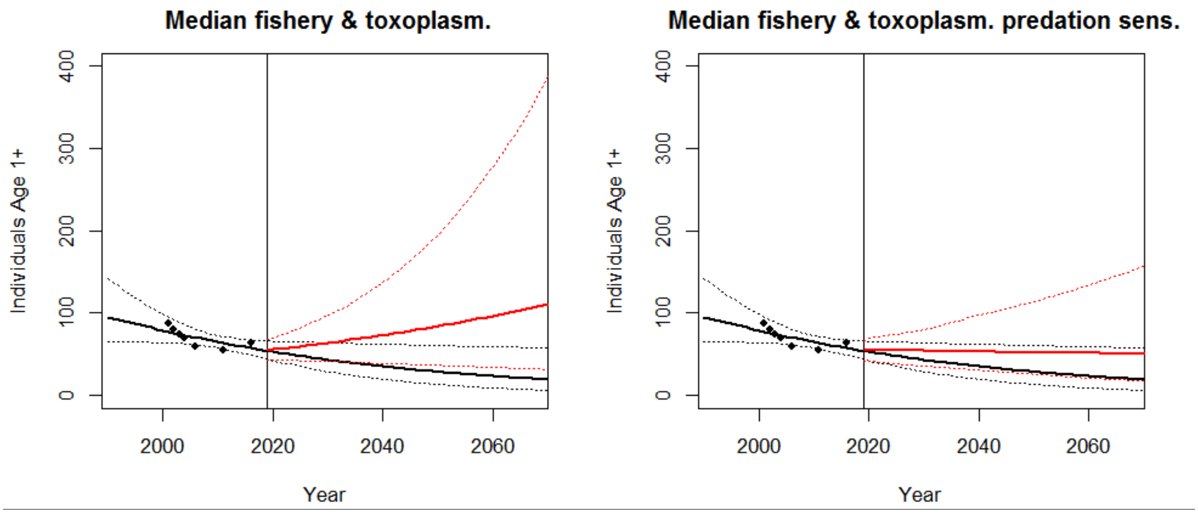


Figure 6.14: Māui dolphin population projections with alternative assumptions with respect to alleviating future threat-specific annual deaths (from Roberts et al. 2019b). Current year (2019) is highlighted by vertical line. To the left of this line: black lines are the median and 95% CI of MCMC estimates of non–calf population trajectory; and census estimates are indicated by black points. To the right of the vertical line: black lines are the projected population trajectory for a model continuing recent demographic rates. Projections ***alleviating*** threat-specific mortality are shown in red: median estimates of annual set net and trawl deaths (top left); the upper 95% estimates of annual set net and trawl deaths (top right); the median fishery deaths and toxoplasmosis, assuming equal detection probability of non–fishery causes of death (bottom right); and the median fishery deaths toxoplasmosis, assuming 10–fold decrease in detection probability of predation mortality (bottom left). For all trajectories, the three lines represent median and 95% CI of MCMC estimates. (Continued)

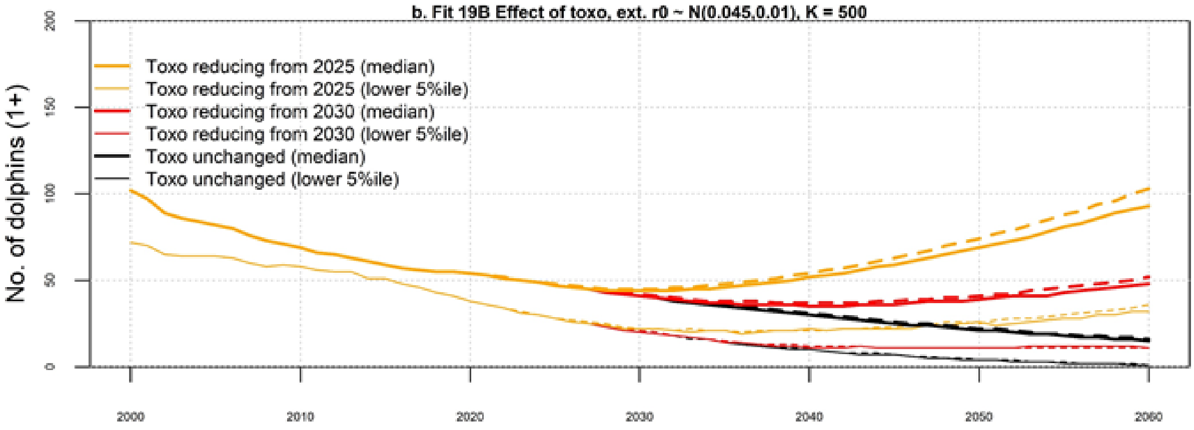


Figure 6.15: Māui dolphin population projections from Cooke et al. (2019) simulating effects of alleviating toxoplasmosis on different time frames (median and lower fifth percentile; solid lines) and eliminating commercial fisheries risk (dashed lines). This figure illustrates a model run under assumption set 'd' described in section 6.5.2, under which fisheries deaths are as estimated by Roberts et al. (2019a) and toxoplasmosis risk levels are estimated independently using North Island necropsy results.

On this basis, the model described by Cooke et al. (2019) suggests that one or more non-commercial fisheries threats may collectively be responsible for 3–4 Māui dolphin deaths per year. Assuming that toxoplasmosis is the sole non-commercial-fisheries threat, population projections under assumption set d) estimated that action to reduce the impact of toxoplasmosis would need to be successful within 5–10 years if Māui dolphins are to avoid the risk of extinction (Figure 6.15). In these simulations, toxoplasmosis risk is assumed to be constant in time beginning in 2000 and continuing until such time as risk reduction efforts begin to take effect, in either 2025 or 2030. The black line assumes no reduction in toxoplasmosis risk; the red and orange lines assume that toxoplasmosis risk is reduced by half each decade, beginning either in 2030 or 2025, respectively. The relative effect of also eliminating fisheries risk as estimated by Roberts et al. (2019a) is also shown.

Note that all of these sets of model runs assumed that excess deaths from all causes except commercial fisheries are constant over time. However recreational fishing risk may have been substantial prior to 2008 but mostly eliminated thereafter, raising the possibility that at least a portion of those 3–4 excess deaths attributed here to toxoplasmosis were actually attributable to recreational fishing and have already been eliminated. Such a hopeful interpretation is consistent with the results of Roberts et al. (2019b) in which adult survival was estimated to have improved in the period after 2008. However this result is highly uncertain, effectively fitting to a single data point from the genetic census of Baker et al. (2016b) suggesting a slight population increase between 2010 and 2015 (but with overlapping confidence intervals). Results of a repeat genetic census in 2020–21 will help to resolve these uncertainties.

6.5.3 CHARACTERISATION OF DOLPHIN DEATHS RECORDED IN DOC INCIDENTS DATABASE

Further characterisation of beach-cast dolphins in the DOC Hector's and Māui dolphin incidents database was undertaken to search for patterns potentially indicative of the nature and magnitude of lethal impacts on the dolphins, and of potential biases arising from use of these data to infer cause of death (Roberts in prep). This analysis found evidence for strong seasonality in the proportion of recovered carcasses attributed to different causes of death. Causes of death showing strong seasonality included entanglement mortalities in fishing gear (primarily in summer), disease mortality (late winter/early spring), neonate deaths (summer), and other mortality categories (variable across seasons; Roberts, unpublished data).

Other patterns were suggestive of seasonal threats that differentially affected dolphins by sex. Most significantly, among non-calf beach-cast carcasses in late winter and early spring months (August to October), and for which the sex was determined, 29 of 35 carcasses were female (Figure 6.16). The corresponding proportion of females (0.83) was significantly different from 0.50 ($p < 0.001$, 2-sided). This is coincident with the period in which all known toxoplasmosis mortalities have occurred to date (September-November). The female bias in mortalities during early spring was evident from 2000 to 2020, but not in the preceding period (Figure 6.17), potentially suggesting a change over time in the impact of whatever threat is responsible for this pattern. Increased carcass recovery rates in winter and early spring, and increased resourcing for necropsy programmes, may help to identify and understand the full range of threats affecting Hector's and Māui dolphins.

There was only tentative, non-significant evidence for changes in the demographic composition of fishery entanglement mortalities with the implementation of different fishery area restrictions around New Zealand. Fewer females were confirmed amongst incidental mortalities since the implementation of wide-ranging fishing restrictions in 2008–09, although a large component of the mortalities during this period that were in the database were not necropsied and sexed. Further analysis of stored tissue samples to sex and, if possible, age these animals may reveal important information.

The study by Roberts (in prep) also developed a rudimentary proxy for seasonal carcass detection probability, based on seasonal public beachgoer count data. This suggested that carcass detection probability is likely to be highly seasonal, such that threats that primarily kill dolphins outside the summer period (e.g., diseases) will be under-represented in the beach-cast sample of dolphins relative to those that kill dolphins in summer (e.g., bycatch and the separation of neonates from their mothers). This conclusion highlights the importance in particular of improving data collection to better understand whatever threats are responsible for the preponderance of female deaths in late winter/early spring. If seasonal detection bias results in these carcasses being under-represented in the beach-cast and necropsied sample, this may produce a negative bias in the associated threat-specific risk estimates.

6.5.4 PREVIOUS DEMOGRAPHIC POPULATION MODELS

A number of modelling exercises have aimed to assess the effect of various proposed management approaches on the future population trajectory of Hector's and Māui dolphins. (Martien et al. 1999, Burkhart & Slooten 2003, Slooten 2007, Slooten & Dawson 2010, Davies & Gilbert 2003, Davies et al. (2008).

The various models share some necessary similarities given the available information:

- each assumes a particular form of population model and uses this to project dolphin numbers forward and backward from a single population estimate;

- none of the models used the most recent aerial survey derived estimates of abundance and distribution in SCSI and ECSI;
- none of these models used spatially explicit estimates of overlap with fisheries to estimate encounter rate and capture rate per encounter, instead a single estimate of dolphin capture rate from the ECSI was applied to historical fishing effort levels to estimate fishing-related dolphin mortalities in other subpopulations.

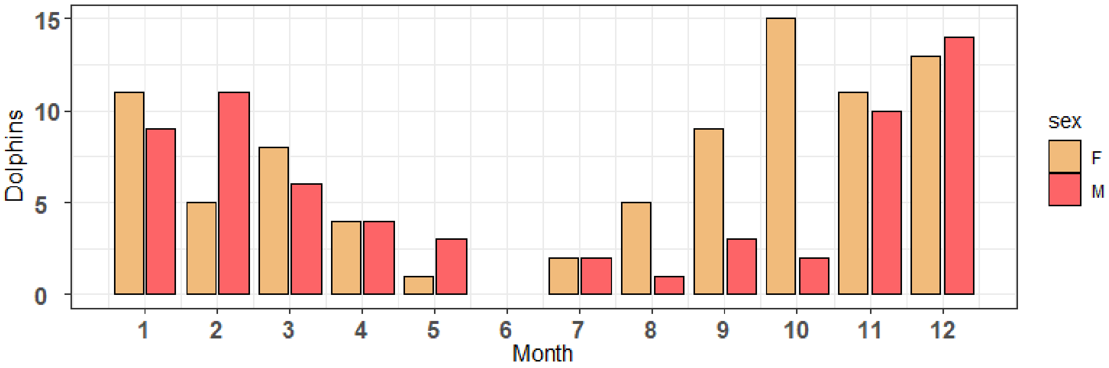


Figure 6.16: Sex composition of adult Hector's or Māui dolphins found beach-cast (dead on shore) since 1984/85, by month of reporting. This plot excludes juveniles and individuals for which the sex was not determined, and a small number of records prior to 1984/85.

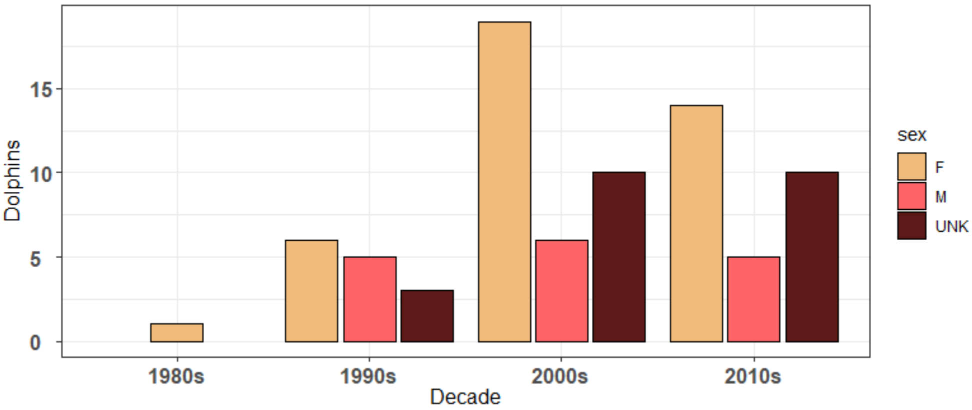


Figure 6.17: Sex composition of Hector's or Māui dolphins found beach-cast (dead on shore) in late winter and spring (August to November) by decade. This plot excludes a small number of records prior to 1984/85. Reproduced from Roberts (2020).

In multiple rounds of review and discussion, the AEWG identified that both forward and rearward population projections using many of these models were reliant on informative priors or strong structural assumptions, and may be sensitive to input parameters that derive from earlier analyses that may become dated, in particular if input parameterisation was a function of population size, or dependent on assumptions about population productivity (r^{max}). The AEWG noted that model estimates were likely to be more reliable for local dolphin populations near Banks Peninsula where most of the data was collected, but the population size or spatial scale to which model outputs could be safely applied was not always clear. The AEWG concluded that if the outputs of these analyses were to be communicated to managers, it should be with appropriate caveats.

6.5.5 BANKS PENINSULA DEMOGRAPHIC MARK-RECAPTURE

Demographic models and analyses based on an ongoing mark-recapture database of dolphins sighted near Banks Peninsula have produced a number of potentially valuable publications to understand population dynamics of Hector's dolphins (e.g., Cameron et al. 1999, Du Fresne 2005; Gormley et al. 2012). In particular the conclusions of Gormley et al. (2012) are frequently cited to infer fisheries mortality rates before and after the establishment of a spatial fisheries closure, but the spatial scale over which the apparent demographic signals are indicative of actual population dynamics has been unclear.

In 2020 MacKenzie & Roberts (in prep) analysed mark-recapture data given in the appendix of Du Fresne (2005), collected around Banks Peninsula from 1985 to 2002. The purpose of the analysis was to evaluate the sensitivity of the findings of Gormley et al. (2012) to alternative model structures. Gormley et al. (2012) analysed data for the period 1986–2006, sourced from the same database as Du Fresne (2005), and reported evidence of increased survival from 1990 onwards, which was interpreted as evidence for the beneficial effects of the Banks Peninsula Marine Mammal Sanctuary. The data used by Gormley et al. (2012) were unavailable for the reanalysis, hence the data from Du Frense (2004) were used for the period 1986–2002. Although the datasets are similar they are not identical for the overlapping time periods.

MacKenzie & Roberts (in prep) found that survival estimates could be sensitive to the model fit to the data, and that the structure used by Gormley et al. (2012) had greater support on the basis of leave-one-out information criterion (LOOIC; Gelman et al. 2014). Importantly, the survival estimates obtained by MacKenzie & Roberts (in prep) were substantially higher than those by Gormley et al. (2012) pre-1990, and slightly lower than Gormley's for post-1990, suggesting an overall decline in survival or occupancy from 1990 onwards. This is at odds with the results of Gormley et al. (2012), (Figure 6.18), but in keeping with the results of Cameron et al. (1999) who also estimated higher pre-1990 survival than Gormley et al. (2012).

The reversal of the apparent change in adult survival relative to the assessment by Gormley et al. (2012) was because different subsets of the mark-recapture data were included in these different analyses over time. It appears that the dataset available to the analysis by MacKenzie & Roberts (in prep) included some dolphin re-sights that had been used by Du Fresne (2005) but were reclassified or otherwise excluded from later mark-recapture analyses by Gormley et al. (2012). Researchers at Otago University report that data selection for inclusion in different analyses has changed over time to more robustly estimate adult survival rates for different subsets of the population. However the nature and consequences of these changes have not always been well documented.

MacKenzie & Roberts (in prep) noted that clarification is required on the following points to resolve conflicting estimates of how Hector's dolphin survival may have changed with the establishment of the BPMMS. Until that time, the authors judged, and the AEWG concurred, that any of the pre-1990 survival estimates from various sources should be regarded as provisional and not yet verified for use to inform management or policy decisions.

The following clarifications were requested:

- details on the spatial distribution of survey effort and dolphin sightings, and how that has changed over time.
- details on the number of individuals that have been reclassified or otherwise excluded, and which sightings are affected.
- sensitivity of the estimated time series of survival estimates to temporal changes in the spatial distribution of survey effort.
- sensitivity of any results to the spatial and temporal sub-setting of the full dataset for analyses.

The long-term mark-recapture data collected near Banks Peninsula are currently (June 2020) being analysed by researchers at Otago University. When these analyses are complete they will provide a significantly longer time series than has been available for any previous analysis estimating Hector's dolphin adult survival rates.

6.5.6 KEY AREAS OF UNCERTAINTY IN THE SPATIAL MULTI-THREAT RISK ASSESSMENT

6.5.6.1 SPATIAL UNCERTAINTY

The following are identified as areas where the outputs of the spatial multi-threat risk assessment may be more uncertain than elsewhere.

- Low dolphin density areas of Māui dolphin habitat. The spatial estimates of dolphin density are most accurate in locations with more dolphins and become less reliable (in a proportional sense not an absolute sense) in locations with very low dolphin densities. For this reason, fisheries risk estimates may be more uncertain in the following locations:

- inside west coast North Island harbours – the models estimate that dolphins enter the harbours very infrequently, but it’s possible that these estimates are wrong in either direction, including the possibility that dolphins never penetrate the interior of these harbours;
- the northern and southern extreme of the Māui dolphin distribution – the southern extreme is verified by sightings data; the northern extreme is unverified;
- The extreme offshore distribution of the Māui dolphin distribution – the habitat model is well-specified and verified by actual data out to around 10 to 12 nautical miles offshore, but at further ranges it predicts a uniformly low “background” density that never drops to zero even at very far distances offshore. It is likely that the model is overestimating the density of dolphins at distances far offshore.

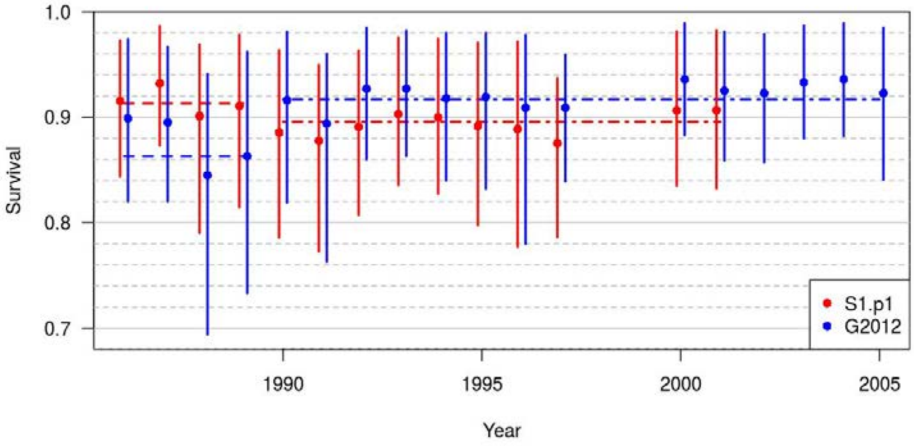


Figure 6.18: Comparison of estimated survival probabilities (mean and 95% c.i.) obtained from the data used by MacKenzie & Roberts (in prep; S1.p1, in red) to those reported by Gormley et al. (2012; G2012, in blue). The Banks Peninsula Marine Mammal Sanctuary was established in 1989; horizontal lines indicate the posterior mean of the mean survival probability from each assessment for the defined pre- and post-sanctuary periods.

- The Cape Egmont to Wellington “transition” zone. Dolphin density estimates are assigned arbitrarily to illustrate what risk dolphins would face if they were resident in this area. It appears instead that dolphin sightings in this area are of transient or dispersing dolphins; actual densities are unknown.

- North coast South Island. The estimated spatial distribution here is more uncertain than the east and west coast South Island subpopulation distributions, due to very few aerial survey observations.

- South coast South Island. The estimated spatial distribution here is more uncertain than the east and west coast South Island subpopulation distributions, due to the absence of a key data layer in the spatial model (representing availability of dolphin prey).

6.5.6.2 POPULATION UNCERTAINTY

At the scale of whole subpopulations, the west, east, and south coast South Island subpopulations and Māui dolphin populations are estimated using consistent methods for which estimates of statistical uncertainty are thought to be accurate and unbiased. However:

- North coast South Island population size. Very little is known about how many dolphins there are in the north coast South Island subpopulation. Uncertainty about population size means that estimates of total deaths are also uncertain but estimates of risk (that is, probability of death per individual animal) are unaffected.

Local population sizes in other locations with low population density may be poorly estimated by aerial surveys.

6.5.6.3 FISHERIES RISK UNCERTAINTY

Set net catchability (probability of capture per encounter) is well estimated. Trawl catchability is estimated with less precision but is known to be much lower than for set nets in an absolute sense. However:

- Cryptic mortalities (unobservable captures) are uncertain for set net fisheries.

- The number of animals dying per trawl event is not well estimated. Evidence suggests that trawl captures may arise from social interactions that sometimes involve more than one dolphin. The model run currently used to inform the TMP assumes that each trawl capture event kills two dolphins on average, but this multiplier is uncertain.

- Fishery groups. All set net fisheries are treated as a single group, and all inshore trawl fisheries are treated as a single group, for purposes of estimating catchability. If some fishers use different gear, or have consistently different behaviour in ways that affect dolphin catchability, then this contrast will not be reflected in local risk estimates. However, unless fisheries observer coverage is also biased, the result will be increased uncertainty but not systematic bias.

- Harbour set nets. The risk assessment model treats WCNI harbour set nets as if they have the same probability of catching a dolphin as do set nets in offshore areas. This approximation may not be valid, so the estimate of risk in harbours is more uncertain than reflected numerically.

- Recreational fisheries risk is not estimated quantitatively. In areas where recreational fishing is still permitted, this could be a substantial but unquantified cause of death. In areas where recreational fisheries previously occurred, but were subsequently eliminated, this could cause a major historical change in threat level that the model is unable to estimate.

6.5.6.4 NON-FISHERIES RISK UNCERTAINTY

The use of beach-cast dolphin carcasses to estimate rates of death relies on assumptions about the rate that carcasses are recovered for necropsy and may be biased. As a consequence:

- Toxoplasmosis death estimates are more uncertain than represented in the numerical estimates and could be biased either high or low due to factors affecting carcass detection rate.

- A possible sex bias in toxoplasmosis deaths (if more females are dying) may have important implications; if the sex bias is real, then toxoplasmosis risk is higher than estimated by Roberts et al. (2019a).

Brucellosis is grouped under 'other' causes of death in Roberts et al. (2019a) hence effectively treated as a component of natural mortality. If brucellosis risk is related to anthropogenic causes or affects some subpopulations in particular, then this treatment may underestimate the importance of this threat.

Non-lethal habitat disruptive threats cannot be quantified:

- Seismic risks from underwater sound are estimated in the risk assessment in a relative sense only, and only for Māui dolphins. Although the level of sound the dolphins experience has been estimated quantitatively, it is unknown how this level of sound may affect dolphins.

6.6 MANAGING FISHERIES AND NON-FISHERIES RISK

The following section describes management tools and measures already in place to manage fisheries and non-fisheries risks to Māui and Hector's dolphins (as of June 2020). These measures do not reflect new management under a revised TMP in 2020; options for such measures are currently being considered by Ministers.

To reduce fisheries risk to Hector's and Māui dolphins, restrictions on commercial and recreational set net, driftnet and trawl fisheries have been established under both the Marine Mammals Protection Act 1978 and Fisheries Act 1996. The first protected area designated for this purpose was with the establishment of a sanctuary at Banks Peninsula in 1988. In 2007, the Hector's and Māui dolphin Threat Management Plan (TMP) was developed by DOC and the former Ministry of Fisheries and included restrictions under the Fisheries Act. Subsequently four additional Marine Mammal Sanctuaries were established in 2008; note however that spatially these later MMS designations were wholly contained within the boundaries of existing fisheries closures (below) so had the effect of managing non-fishery risks rather than further reducing fisheries risk.

6.6.1 MARINE MAMMAL SANCTUARIES

1) The *Bank's Peninsula Marine Mammal Sanctuary* was established in 1988, the first Hector's dolphin sanctuary. This region on the east coast of the South Island is a dolphin hotspot and was subject to high levels of bycatch from recreational and commercial set nets at least from the 1970s, until at least as recently as the mid-1980s (Dawson 1991, Dawson & Slooten 1993). The sanctuary was extended in 2008 and now covers 389 km of coastline, extending from the southern end of the Rakaia River mouth to the northern end of the Waipara River mouth and out to 12 nm (22.2 km) offshore.

2) The *Clifford and Cloudy Bay Marine Mammal Sanctuary* was established in 2008 and covers an area of 338 km of coastline from Cape Campbell to a point 12 nm (22.2 km) offshore in a direct line to Tory Channel, northeast South Island. This region is an area with relatively high numbers of Hector's dolphins observed over 20 km offshore (Du Fresne & Mattlin 2009, MacKenzie & Clement 2014, Hamner et al. 2017).

3) The *Catlins Coast Marine Mammal Sanctuary* was established in 2008, covering an area with small, genetically isolated populations of Hector's dolphins from Porpoise Bay and Toetoes Bay, southeast South Island (Bejder & Dawson 2001, Hamner et al. 2012, MacKenzie & Clement 2018). The sanctuary covers 161 km of coastline extending from Three Brother's Point offshore 5 nm (9.3 km) to a point 6.9 nm (12.8 km) offshore from Bushy Point Beacon.

4) The *Te Waewae Bay Marine Mammal Sanctuary* was established in 2008, covering 113 km of Southland coastline. The boundaries encompass Te Waewae Bay from Pahia Point to Sand Hill Point into shore. This sanctuary covers the main habitat and most of the population of the genetically distinct SCSI population of Hector's dolphins (Hamner et al. 2012, Rodda & Moore 2013, MacKenzie & Clement 2019).

5) The *West Coast North Island Marine Mammal Sanctuary* was established in 2008 and is the largest, covering 2164 km of coastline from Maunganui Bluff, Northland to Oakura, Taranaki. In 2013, there was an amendment under the Marine Mammals Protection Act 1988 to the activities restricted within a portion of the sanctuary due to a new abundance estimate and bycatch event off Taranaki. This is the most complex of the protected areas; under the Fisheries Act 1996, commercial and recreational set net, driftnet, and trawl restrictions are in place with variations by location. Protection also includes an intensive fisheries observer programme for the set net fisheries in the southern Taranaki region, and trawl fisheries between Maunganui Bluff and Pariokariwa Point.

6.6.2 SPATIAL CLOSURES UNDER THE FISHERIES ACT

In 2008, an extensive package of spatial closures was implemented under the Fisheries Act to reduce fisheries risk to dolphins, largely superseding the existing discrete closures under the Marine Mammal Protection Act. In the North Island these restrictions were extended further in 2012 and 2013. Current spatial fisheries closures are depicted in Figures 6.19–6.22 and described below.

On the WCNI, the set net restrictions on were extended to 7 nm offshore between Maunganui Bluff and Pariokariwa Point (including the entrances to the Kaipara, Manukau, and Raglan harbours and the entrance to the Waikato River). Trawling was prohibited to 2 nm offshore between Maunganui Bluff and Pariokariwa Point, and to 4 nm offshore between Manukau Harbour and Port Waikato. In 2012, the set net restrictions on the WCNI were extended further south, banning commercial and recreational set netting to 2 nm offshore from Pariokariwa Point to Hawera. New requirements were also implemented requiring an MPI observer on any commercial set net vessel operating within 7 nm of shore. In 2013, the set net restrictions were extended again, banning commercial and recreational set netting between 2 and 7 nm from Pariokariwa Point to the Waiwhakaiho River mouth.

On the ECSI and SCSI, most set netting was prohibited within 4 nm of the coast, and trawling within 2 nm offshore was limited only to trawl vessels employing nets with a low headline height (generally targeting flatfish) on the presumption that dolphin catchability using low headline height gear is likely to be lower[17].

---

[17] Detailed descriptions of the restrictions can be found at: Ministry for Primary Industries. Protecting Hector's and Māui dolphins. Retrieved from https://www.mpi.govt.nz/protection-and-response/sustainable-fisheries/managing-our-impact-on-marine-life/protecting-hectors-and-maui-dolphins.

On the WCSI, recreational set netting was banned within 2 nm of the coast and commercial set netting was subject to a seasonal restriction (Figure 6.20).

6.6.3 OPTIONS FOR FISHERIES RISK MITIGATION

To date most management of fisheries risk to Hector’s and Māui dolphins has emphasized spatial management, to reduce the overlap between dolphins and fishing effort distributions. Other options for gear modifications aimed at reducing cetacean captures in set net fisheries include changing the way that fishing gear is deployed to reduce the risk of entanglement (e.g., Hembree & Harwood 1987) or adding acoustic alarms (pingers) to alert dolphins to the presence of the gear (Dawson et al. 2013b). Some ECSI set net fishermen use pingers under a voluntary Code of Practice (Southeast Finfish Management Company 2000). The effectiveness of pingers has been demonstrated in some experimental trials for other small cetaceans (e.g., Kraus et al. 1997, Trippel et al. 1999, Bordino et al. 2002; see review in Dawson et al. 2013b); however their utility is not universal, for example because cetaceans can become habituated to their presence (Cox et al. 2001) or because they are not always properly deployed (Cox et al. 2007, Dawson et al. 2013b).

To address fisheries risk in trawl fisheries, Fisheries New Zealand is progressing new research (under project SEA2019-27) to investigate options for deployed hydrophone arrays that can detect the vocalisations of the dolphins during fishing operations, to better understand interactions between dolphins and fishing gear. Outcomes of this work will be used to inform further investigations of potential trawl risk mitigation systems, e.g., to alert fishers in real time to the presence of dolphins near the gear.

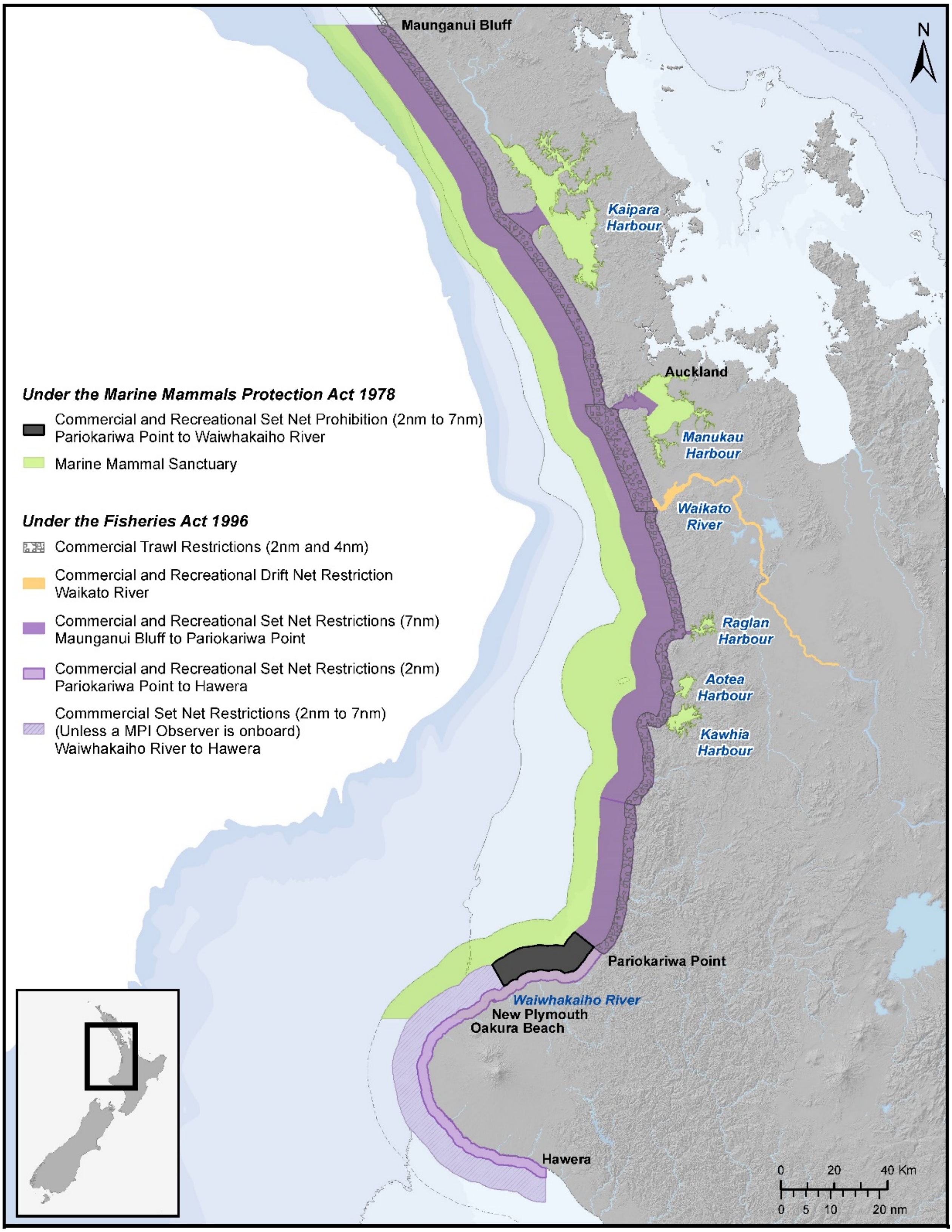
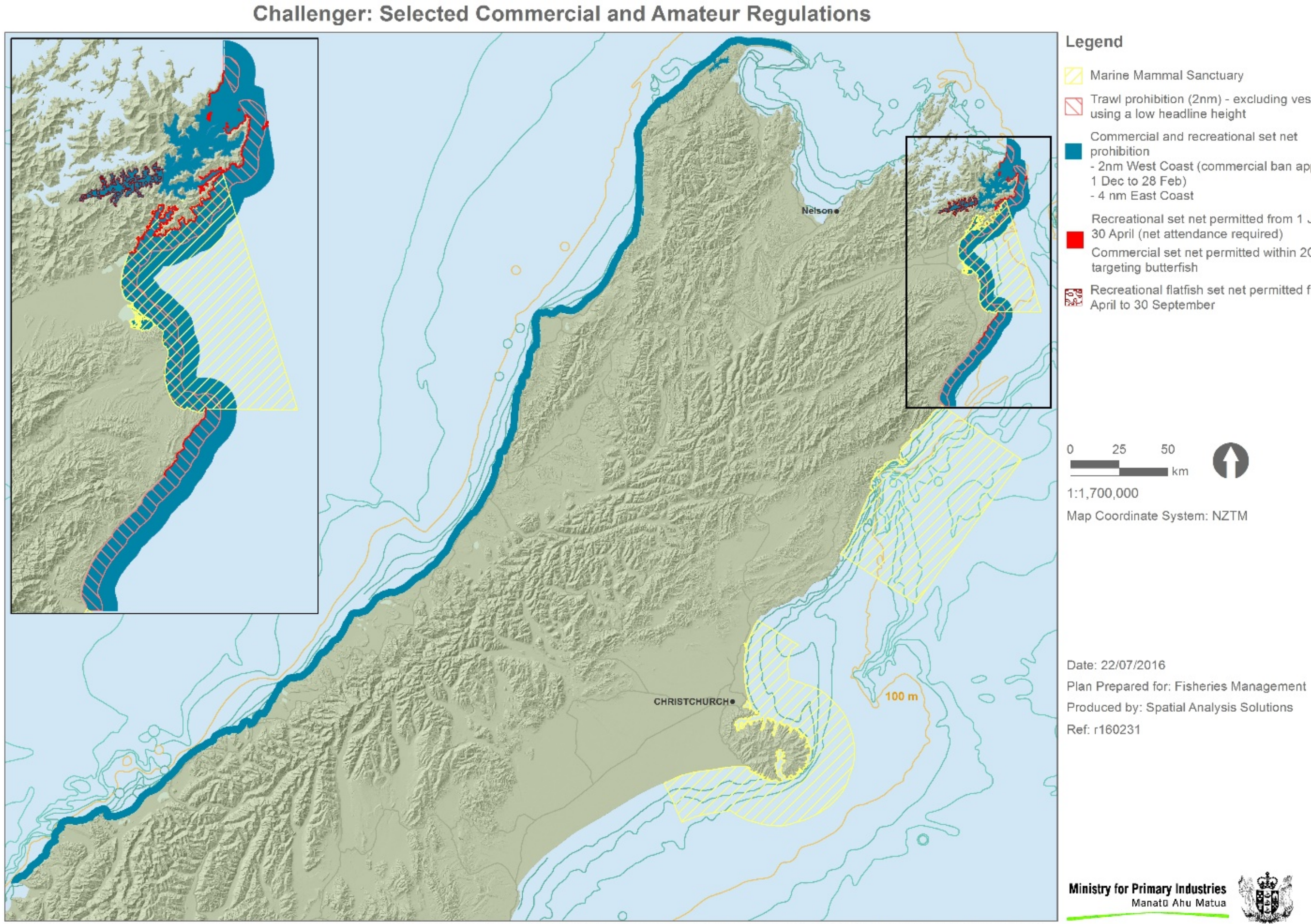


Figure 6.19: Summary of restrictions on commercial and amateur set netting on the WCNI. For a full description of the restrictions, see: Ministry for Primary Industries. Protecting Hector’s and Māui dolphins. Retrieved from https://www.mpi.govt.nz/protection-and-response/sustainable-fisheries/managing-our-impact-on-marine-life/protecting-hectors-and-maui-dolphins.



Disclaimer: This map and all information accompanying it (the "Map") is intended to be used as a guide only, in conjunction with other data sources and methods, and should only be used for the purpose for which it was developed. The information shown in this Map is based on a summary of data obtained from various sources. While all reasonable measures have been taken to ensure the accuracy of the Map, MPI: (a) gives no warranty or representation in relation to the accuracy, completeness, reliability or fitness for purpose of the Map; and (b) accepts no liability whatsoever in relation to any loss, damage or other costs relating to any person's use of the Map, including but not limited to any compilations, derivative works or modifications of the Map. Crown copyright ©. This map is subject to Crown copyright administered by Ministry for Primary Industries (MPI). Data Attribution: This map uses data sourced from LINZ under CC BY and © Geographx.

Figure 6.20: Summary of restrictions on commercial and amateur set netting, and commercial trawling in the Challenger area (west coast) and north-east coast of the South Island. For a full description of the restrictions, see: Ministry for Primary Industries. Protecting Hector’s and Māui dolphins. Retrieved from https://www.mpi.govt.nz/protection-and-response/sustainable-fisheries/managing-our-impact-on-marine-life/protecting-hectors-and-maui-dolphins.

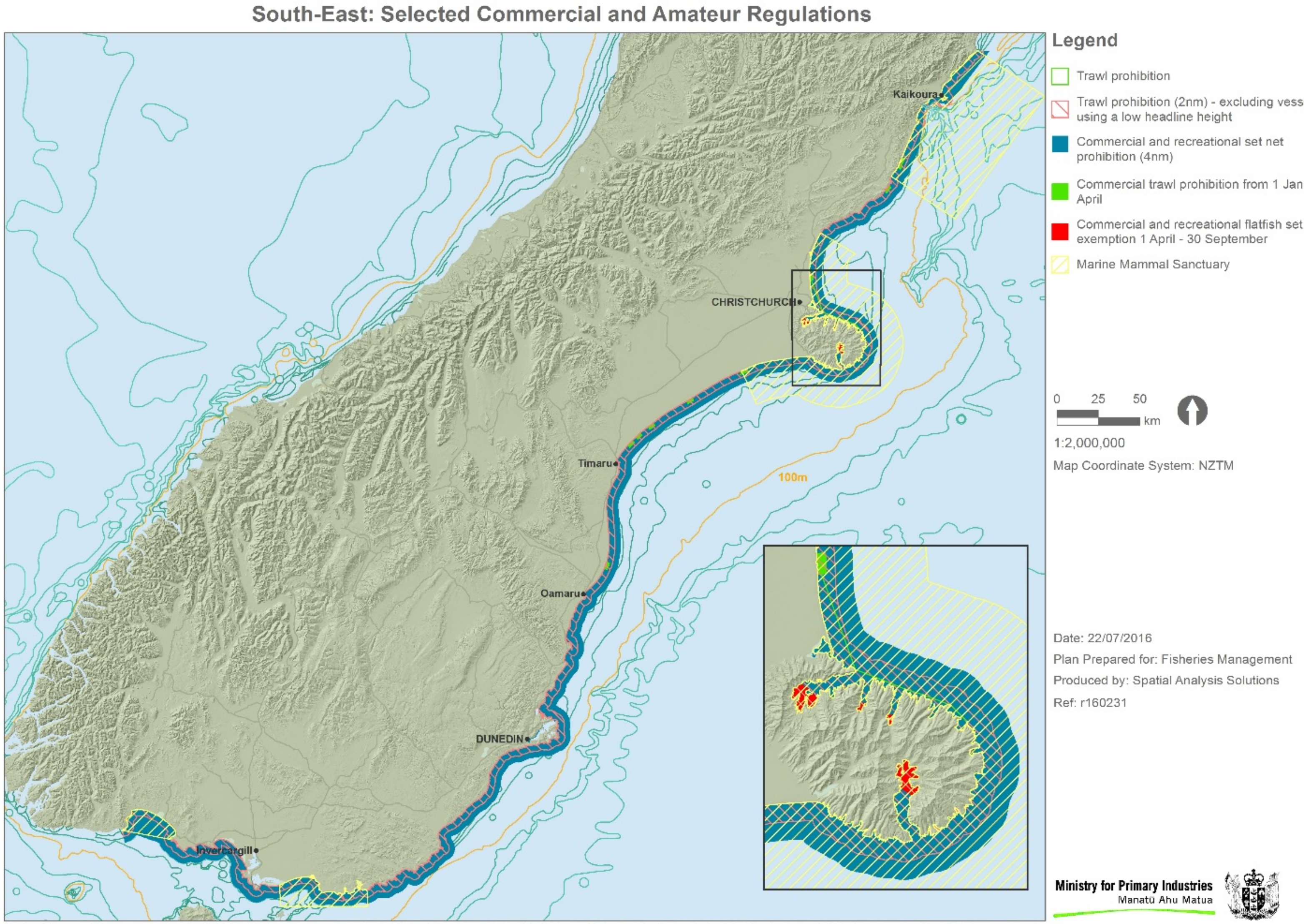


Figure 6.21: Summary of restrictions on commercial and amateur set netting, and commercial trawling in the south-east of New Zealand. For a full description of the restrictions, see: Ministry for Primary Industries. Protecting Hector’s and Māui dolphins. Retrieved from https://www.mpi.govt.nz/protection-and-response/sustainable-fisheries/managing-our-impact-on-marine-life/protecting-hectors-and-maui-dolphins.

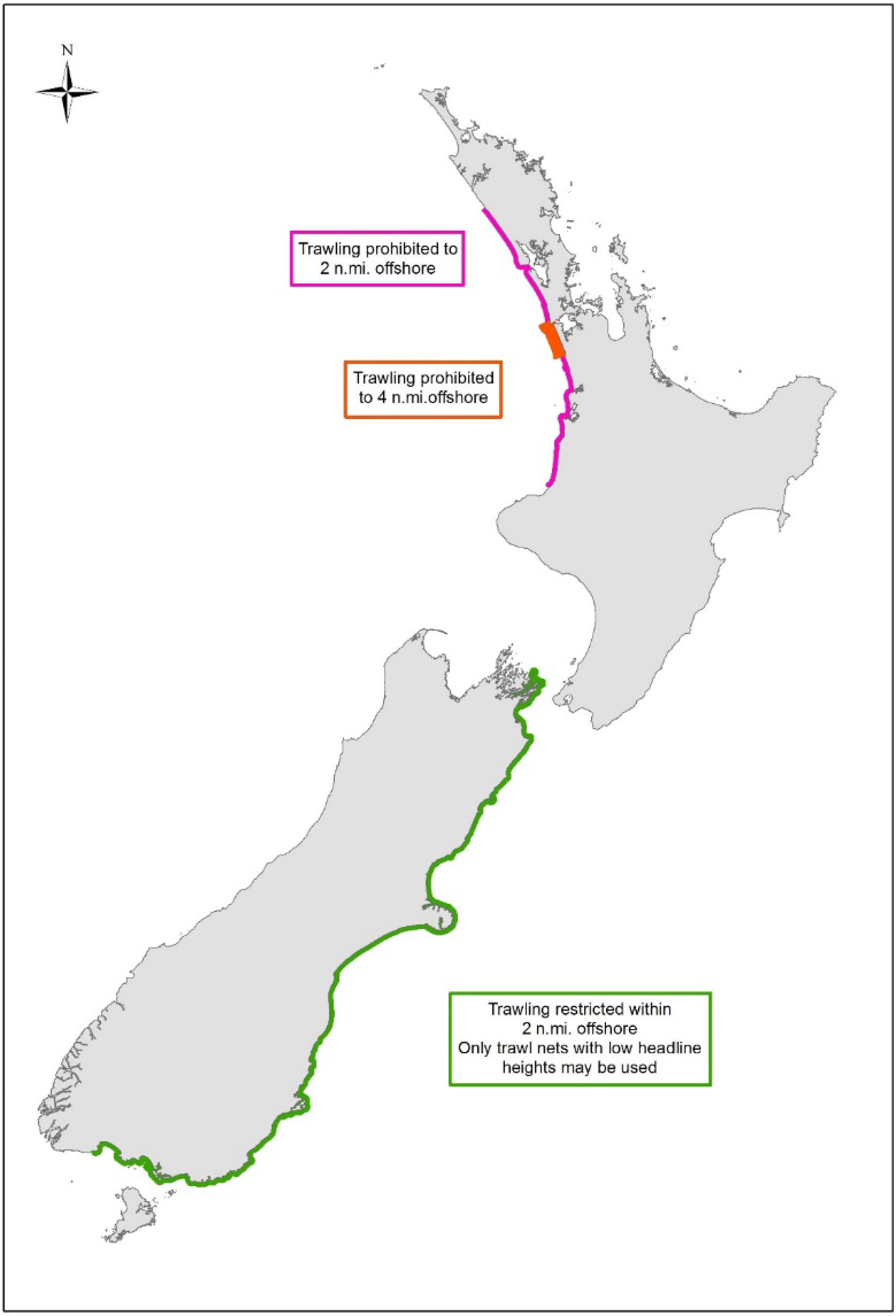


Figure 6.22: Summary of restrictions on trawling. For a full description of the restrictions see: Ministry for Primary Industries. Protecting Hector's and Māui dolphins. Retrieved from https://www.mpi.govt.nz/protection-and-response/sustainable-fisheries/managing-our-impact-on-marine-life/protecting-hectors-and-maui-dolphins.

6.7 INDICATORS AND TRENDS

Population size	**Māui dolphins**: 55 (95% c.i.: 48–69) in 2010–11[18] 63 (95% c.i.: 57–75) in 2015–16[19] **ECSI Hector's dolphins**: Annual median estimate: 8968 (s.e.: 1377; 95% c.i.: 6649–12 096) Seasonal estimate: 9728 (CV: 17%; 95% c.i.: 7001–13 517) in summer 2012–13 and 8208 (CV 27%; 95% c.i.: 4888–13 785) in winter 2013 (out to 20 nm)[20] **WCSI Hector's dolphins**: Annual estimate: 5388 (CV = 21%; 95% c.i.: 3613–8034) in 2000–01 (out to 4 nm)[21] Annual median estimate: 5642 (s.e.: 936; 95% c.i.: 4085–7792) Seasonal estimate : 5490 (CV: 26%; 95% c.i.: 3319–9079) in summer and 5802 (CV: 21%; 95% c.i.: 3879–8679) in winter (out to 20 nm)[20] **SCSI Hector's dolphins**: Annual median estimate: (95% c.i. = 217-508) in 2018 Seasonal estimates: 177 (CV: 37%; 95% c.i.: 88–358) in March 2011; 299 (CV: 47%; 95% c.i.: 125–714) in August 2011[20]
Population trend	**Māui dolphins**: Declining over longer time period although some evidence of possible stabilisation from 2010/11 to 2015/16. **ECSI Hector's dolphins**: Unknown. Inconsistent evidence from abundance estimates, risk analyses and demographic estimates of population growth rates. **SCSI Hector's dolphins**: Unknown. Population size estimated but too uncertain to discern trend **WCSI Hector's dolphins:** Unknown; Population estimated but too uncertain to discern trend **NCSI Hector's dolphins**: Unknown; population size unknown
Threat status	**Māui dolphins**: NZ: Nationally Critical, Criterion A(1), Conservation Dependent in 2013[22] IUCN: Critically Endangered, Criteria A4c,d and C2a(ii) in 2013[23] **Hector's dolphins**: NZ: Nationally Vulnerable, Criterion D(1/1), Conservation Dependent in 2018 IUCN: Endangered, Criterion A4d in 2013[23]
Number of fisheries deaths (includes cryptic deaths)	Hector's dolphin set net: 44 (21–80) Hector's dolphin trawl: 14 (1–43) Māui dolphin set net: 0.10 (0–0.25) Māui dolphin trawl: 0.02 (0–0.05)
Trends in interactions	Hector's dolphin set net: stable Hector's dolphin trawl: decreasing Māui dolphin set net: decreasing Māui dolphin trawl decreasing [see Figure 6.9]

6.8 REFERENCES

Abel, R S; Dobbins, A G; Brown, T (1971) *Cephalorhynchus hectori* subsp. *bicolor* sightings, capture, captivity. *Investigations on Cetacea* 3: 171–179.

Abraham, E R; Berkenbusch, K; Neubauer, P; Richard, Y (2017) Assessment of the risk to New Zealand marine mammals from commercial fisheries. *New Zealand Aquatic Environment and Biodiversity Report No. 189*. 123 p.

Archipelago Marine Research Ltd (2013) Using Electronic Monitoring to document inshore set net captures of Hector's dolphins. Report prepared for Ministry for Primary Industries. Retrieved from http://www.mpi.govt.nz/document-vault/14044.

Baird, S J; Bradford, E (2000) Estimation of Hector's dolphin bycatch from inshore fisheries, 1997/98 fishing year. Department of Conservation, Wellington. 28 p.

Baker, A N (1972) New Zealand whales and dolphins. *Tuatara 20*: 1–49.

---

[18] Hamner et al. (2012b)

[19] Baker et al. (2019)

[20] MacKenzie & Clement (2019)

[21] Slooten et al. (2004)

[22] Baker et al. (2019)

[23] Reeves et al. (2020)

Baker, A N (1978) The status of Hector's dolphin *Cephalorhynchus hectori* (van Beneden) in New Zealand waters. *Reports of the International Whaling Commission 28*: 331–334.

Baker, A N; Smith, A N H; Pichler, F B (2002) Geographical variation in Hector's dolphin: recognition of a new subspecies of *Cephalorhynchus hectori*. *Journal of the Royal Society of New Zealand 32*: 713–717.

Baker, C S; Boren, L; Childerhouse, S; Constantine, R; van Helden, A; Lundquist, D; Rayment, W; Rolfe, J R (2019) Conservation status of New Zealand marine mammals, 2019. *New Zealand Threat Classification Series 29*. Department of Conservation, Wellington. 18 p.

Baker, C S; Chilvers, B L; Childerhouse, S; Constantine, R; Currey, R; Mattlin, R; van Helden, A; Hitchmough, R; Rolfe, J (2016a) Conservation status of New Zealand marine mammals, 2013. *New Zealand Threat Classification Series 14*. Department of Conservation, Wellington. 18 p.

Baker, C S; Hamner, R M; Cooke, J; Heimeier, D; Vant, M; Steel, D; Constantine, R (2013) Low abundance and probable decline of the critically endangered Māui's dolphin estimated by genotype capture-recapture. *Animal Conservation 16*: 224–233.

Baker, C S; Steel, D; Hamner, R M; Hickman, G; Boren, L; Arlidge, W; Constantine, R (2016b) Estimating the abundance and effective population size of Māui dolphins using microsatellite genotypes in 2015–16, with retrospective matching to 2001–16. Department of Conservation, Auckland. 74 p.

Baker, C S; Steel, D; Hamner, R; Constantine, R; Ogle, M; Tai, A (2017) Note on individual identification, sex and mtDNA haplotypes of Hector's dolphins sampled in Queen Charlotte Sound, with comparison to Golden Bay. Unpublished Progress Report to Department of Conservation. 27 January 2017.

Barbieri, M M; Kashinsky, L; Rotstein, D S; et al (2016) Protozoal-related mortalities in endangered Hawaiian monk seals *Neomonachus schauinslandi*. *Diseases of Aquatic Organisms 121(2)*: 85–95. doi:10.3354/dao03047.

Bejder, L; Dawson, S (2001) Abundance, residency and habitat utilisation of Hector's dolphin (*Cephalorhynchus hectori*) in Porpoise Bay, New Zealand. *New Zealand Journal of Marine and Freshwater Research 35*: 277–287.

Bordino, P; Kraus, S; Albareda, D; Fazio, A; Palmerio, A; Mendez, M; Botta, S (2002) Reducing incidental mortality of franciscana dolphin *Pontoporia blainvillei* with acoustic warning devices attached to fishing nets. *Marine Mammal Science 18*: 833–842.

Bräger, S (1998) Behavioural ecology and population structure of Hector's dolphin (*Cephalorhynchus hectori*). Unpublished PhD Thesis, University of Otago, Dunedin, New Zealand. 168 p.

Bräger, S (1999) Association patterns in three populations of Hector's dolphin, *Cephalorhynchus hectori*. *Canadian Journal of Zoology 77(1)*: 13–18. https://doi.org/10.1139/z98-192.

Bräger, S; Bräger, Z (2018) Range utilization and movement patterns of coastal Hector's dolphins (*Cephalorhynchus hectori*). Aquatic Mammals 44 (6): 633–642.

Bräger, S; Dawson, S M; Slooten E; Smith, S; Stone, G S; Yoshinaga, A (2002) Site fidelity and along-shore range in Hector's dolphin, an endangered marine dolphin from New Zealand. *Biological Conservation 108*: 281–287.

Bräger, S; Harraway, J; Manly, B F J (2003) Habitat selection in a coastal dolphin species (*Cephalorhynchus hectori*). *Marine Biology 143*: 233–244.

Bräger, S; Schneider, K (1998) Nearshore distribution and abundance of dolphins along the West Coast of the South Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research 32*: 105–112.

Brough, T; Rayment, W; Slooten, E; Dawson, S (2019) Fine scale distribution for a population of New Zealand's only endemic dolphin (*Cephalorhynchus hectori*) shows long-term stability of coastal hotspots. *Marine Mammal Science 35*(1): 140–163.

Buckle, K; Roe, W D; Howe, L; Michael S; Duignan P J; Burrows E; Ha H J; Humphrey S; McDonald W L (2017) Brucellosis in Endangered Hector's Dolphins (*Cephalorhynchus hectori*). *Veterinary Pathology 54(5)*: 838–845.

Burkhart, S M; Slooten, E (2003) Population viability analysis for Hector's dolphin (*Cephalorhynchus hectori*): a stochastic population model for local populations. *New Zealand Journal of Marine and Freshwater Research 37*: 553–566.

Cameron, C; Barker, R; Fletcher, D; Slooten, E; Dawson, S M (1999) Modelling survival of Hector's dolphins around Banks Peninsula, New Zealand. *Journal of Agricultural, Biological and Environmental Statistics 4*: 126–135.

Cawthorn, M W (1988) Recent observations of Hector's dolphin, *Cephalorhynchus hectori*, in New Zealand. *Reports of the International Whaling Commission Special Issue 9*: 303–314.

Clement, D; Mattlin, R; Torres, L (2011) Abundance, distribution and productivity of Hector's (and Māui's) dolphins. Final Research Report for project PRO2009-01A. (Unpublished report held by the Ministry for Primary Industries, Wellington.)

Clement, D; Slooten, E; Dawson, S; DuFresne, S (2001) Line-transect survey of Hector's dolphin abundance between Farewell Spit and Motunau. *DOC Science Internal Series 22*. Department of Conservation, Wellington. 15 p.

Conrad, P. A; Miller, M A; Kreuder, C; James, E R; Mazet, J; Dabritz, H; Jessup, D A; Gulland, F; Grigg, M E (2005) Transmission of Toxoplasma: clues from the study of sea otters as sentinels of *Toxoplasma gondii* flow into the marine environment. *International Journal for Parasitology 35*: 1155–1168. doi:10.1016/j.ijpara.2005.07.002.

Cooke, J G; Steel, D; Hamner, R M; Constantine, R; Baker, C S (2018) Population estimates and projections of Māui dolphin (*Cephalorhynchus hectori maui*) based on genotype capture-recapture, with implications for management of mortality risk. IWC Scientific Committee doc. SC/67b/ASI5. 16 p.

Cooke, J G; Constantine, R; Hamner, R M; Steel, D; Baker, C S (2019) Population dynamic modelling of the Māui dolphin based on genotype capture-recapture with projections involving bycatch and disease risk. *New Zealand Aquatic Environment and Biodiversity Report No. 216*. 38 p.

Cox, T M; Lewison, R L; Zydelis, R; Crowder, L B; Safina, C; Read, A J (2007) Comparing effectiveness of experimental and implemented bycatch reduction measures: the ideal and the real. *Conservation Biology 21*: 1155–1164.

Cox, T M; Read, A J; Solow, A; Tregenza, N (2001) Will harbour porpoises (*Phocoena phocoena*) habituate to pingers? *Journal of Cetacean Research and Management 3*: 81–86.

Currey, R J C; Boren, L; Sharp, B; Peterson, D (2012) A risk assessment of threats to Māui's dolphins. Ministry for Primary Industries and Department of Conservation, Wellington. 51 p.

Davies, N M; Bian, R; Starr, P; Lallemand, P; Gilbert, D J; McKenzie, J R (2008) Risk analysis of Māui's dolphin and Hector's dolphin subpopulations to commercial set net fishing using a temporal-spatial age-structured model. Ministry of Fisheries, Wellington. 113 p.

Davies, N M; Gilbert, D J (2003) A risk analysis of an endangered dolphin subspecies using a temporal-spatial age-structured model. Final Research Report for Ministry of Fisheries research project MOF2002/03D, Objectives 1, 2 and 3. 42 p. (Unpublished report held by the Ministry for Primary Industries, Wellington.)

Dawson, S; Northridge, S; Waples, D; Read, A J (2013b) To ping or not to ping: the use of active acoustic devices in mitigating interactions between small cetaceans and gillnet fisheries. *Endangered Species Research 19*: 201–221.

Dawson, S M (1991) Incidental catch of Hector's dolphin in inshore gillnets. *Marine Mammal Science 7*: 283–295.

Dawson, S M (2019) *Cephalorhynchus* Dolphins: *C. heavisidii*, *C. eutropia*, *C. hectori*, and *C. commersonii*. pp. 166–172. *In* Encyclopedia of Marine Mammals. Elsevier. http://doi.org/10.1016/b978-0-12-804327-1.00086-8.

Dawson, S M; Slooten, E (1988) Hector's Dolphin *Cephalorhynchus hectori*: Distribution and abundance. *Reports of the International Whaling Commission Special Issue 9*: 315–324.

Dawson, S M; Slooten, E (1993) Conservation of Hector's dolphins: The case and process which led to the establishment of the Banks Peninsula Marine Mammal Sanctuary. *Aquatic Conservation: Marine and Freshwater Ecosystems 3*: 207–221.

Dawson, S M; Slooten, E; DuFresne, S D; Wade, P; Clement, D M (2004) Small-boat surveys for coastal dolphins: Line-transect surveys of Hector's dolphins (*Cephalorhynchus hectori*). *Fishery Bulletin 102*: 441–451.

Derville, S; Constantine, R; Baker, C S; Oremus, M; Torres, L G (2016). Environmental correlates of nearshore habitat distribution by the Critically Endangered Māui dolphin. *Marine Ecology Progress Series 551*: 261–275.

Dillingham, P W; Moore, J E; Fletcher, D; Cortes, E; Curtis, K A; James, K C; Lewison, R L (2016) Improved estimation of intrinsic growth R(max) for long- lived species: integrating matrix models and allometry. *Ecological Applications 26 (1)*: 322–333.

DOC (2020a) Hector's and Māui dolphin incident database. Retrieved from http://www.doc.govt.nz/our-work/hectors-and-maui-dolphin-incident-database.

DOC (2020b) Māui dolphin sightings. Retrieved from http://www.doc.govt.nz/our-work/our-work-with-maui-dolphin/maui-dolphin-sightings.

Du Fresne, S (2005) Conservation biology of Hector's dolphin. PhD Thesis, University of Otago, Dunedin, New Zealand. 166 p.

Du Fresne, S (2010) Distribution of Māui's dolphin (*Cephalorhynchus hectori maui*) 2000–2009. *DOC Research & Development Series 322*. Department of Conservation, Wellington.

Du Fresne, S; Burns, D; Gates, E (2012) An updated, annotated bibliography for Hector's (*Cephalorhynchus hectori hectori*) and Māui's (*C. hectori maui*) dolphins. *DOC Research and Development Series 332*. Department of Conservation, Wellington. 43 p.

Du Fresne, S; Dawson, S; Slooten E (2001) Line-transect survey of Hector's dolphin abundance between Timaru and Long Point, and effect of attraction to survey vessel. New Zealand Department of Conservation

Du Fresne, S; Mattlin, R (2009) Distribution and Abundance of Hector's Dolphin (*Cephalorhynchus hectori*) in Clifford and Cloudy Bays. Final Report for NIWA project CBF07401, prepared for Marine Wildlife Research Ltd.

Duignan, P J; Gibbs, N J; Jones G W (2004) Autopsy of cetaceans incidentally caught in commercial fisheries, and all beachcast specimens of Hector's dolphins, 2001/02. *DOC Science Internal Series 176*. 26 p.

Edwards, C T T; Roberts, J O; Doonan, I J (2018) Estimation of the maximum rate of intrinsic growth for Hector's dolphin. (Unpublished Final Research Report available from Fisheries New Zealand.) 22 p.

Ferreira, S M; Roberts, C C (2003) Distribution and abundance of Māui's dolphins (*Cephalorhynchus hectori maui*) along the North Island west coast, New Zealand. *DOC Science Internal Series 93*. 19 p.

Forney, K A; Southall, B L; Slooten, E; Dawson, S M; Read, A J; Baird, R W; Brownell, R L Jr (2017) Nowhere to go: Noise impact assessments for marine mammal populations with high site fidelity. *Endangered Species Research 32(1)*: 391–413. https://doi.org/10.3354/esr00820.

Freeman, D (2003) A review of records of Hector's dolphins (*Cephalorhynchus hectori*) from the East Coast of the North Island, New Zealand. *East Coast/ Hawkes Bay Conservancy Technical Report Series 11.* Department of Conservation, Gisborne. 13 p.

Geijer, C K; Read, A J (2013) Mitigation of marine mammal bycatch in U.S. fisheries since 1994. *Biological Conservation 159*: 54–60.

Gelman, A; Hwang, J; Vehtari, A (2014) Understanding predictive information criteria for Bayesian models. *Statistics and Computing 24(6)*: 997–1016. https://doi.org/10.1007/s11222-013-9416-2.

Gormley, A M (2009) Population modelling of Hector's dolphin. Unpublished PhD Thesis, University of Otago, Dunedin, New Zealand. 217 p.

Gormley, A M; Dawson, S M; Slooten, E; Bräger, S (2005) Capture-recapture estimates of Hector's dolphin abundance at Banks Peninsula, New Zealand. *Marine Mammal Science 21*: 204–216.

Gormley, A M; Slooten, E; Dawson, S M; Barker, R J; Rayment, W; Du Fresne, S; Bräger, S (2012) First evidence that marine protected areas can work for marine mammals. *Journal of Applied Ecology 49*: 474–480.

Green, E; Charteris, C; Rodda, J (2007) Te Waewae Bay Hector's dolphins: abundance, distribution and threats. Southland Conservancy, Department of Conservation, Invercargill. 54 p.

Hamner, R M; Constantine, R; Mattlin, R; Waples, R; Baker, C S (2013) Genotype capture-recapture estimates of abundance and effective population size of Hector's dolphins in Cloudy Bay, New Zealand. SC/65a/SM07. 65th meeting of the International Whaling Commission Scientific Committee, Jeju, South Korea.

Hamner, R M; Constantine, R; Mattlin, R; Waples, R; Baker, C S (2017) Genotype-based estimates of local abundance and effective population size for Hector's dolphins. *Biological Conservation*, *211 (Part A)*: 150–160.

Hamner, R M; Constantine, R; Oremus, M; Stanley, M; Brown, P; Baker, C S (2014a) Long range genetic movement by Hector's dolphins provides potential genetic enhancement for critically endangered Māui's dolphin. *Marine Mammal Science 30*: 139–153.

Hamner, R M; Oremus, M; Stanley, M; Brown, P; Constantine, R; Baker, C S (2012b) Estimating the abundance and effective population size of Māui's dolphins using microsatellite genotypes in 2010–11, with retrospective matching to 2001–2007. Department of Conservation, Auckland. 48 p.

Hamner, R M; Pichler, F B; Heimeier, D; Constantine, R; Baker, C S (2012a) Genetic differentiation and limited gene flow among fragmented populations of New Zealand endemic Hector's and Māui's dolphins. *Conservation Genetics 13*: 987–1002.

Hamner, R M; Steel, D; Constantine, R; Morrissey, M; Ogle, M; Weir, J; Olavarría, C; Baxter, A; Arlidge, W; Boren, L and Baker C S (2016) Local population structure and abundance of Hector's dolphins off Kaikoura – 2014 and 2015. Report to the New Zealand Department of Conservation – 6 March 2016

Hamner, R M; Wade, P; Oremus, M; Stanley, M; Brown, P; Constantine, R and Scott Baker R (2014b) Critically low abundance and limits to human-related mortality for the Māui's dolphin. *Endangered Species Research* 26: 87-92.

Heithaus, M R (2006) Predator–prey and competitive interactions between sharks (order Selachii) and dolphins (suborder Odontoceti): a review. *Journal of Zoology 253(1)*: 53–68.

Hembree, D; Harwood, M B (1987) Pelagic gillnet modification trials in northern Australian seas. *Reports of the International Whaling Commission 37*: 369–373.

Hodgson, P (2002) South Island Hector's dolphin decisions. Ministry of Fisheries, Wellington. 13 p.

Hunt, S; Jones H F E (2020) The fate of river-borne contaminants in the marine environment: Characterising Regions of Freshwater Influence (ROFIs) and estuary plumes using idealised models and satellite images. *Marine Pollution Bulletin 156*: 111169. https://doi.org/10.1016/j.marpolbul.2020.111169.

International Whaling Commission (2016a) Report of the Scientific Committee. Annex L. Report of the Sub-Committee on Small Cetaceans. *Journal of Cetacean Resource Management (supp) 17*: 357–384.

International Whaling Commission (2016b) Report of the Scientific Committee. 7–19 June 2016, Bled, Slovenia. IWC/6/Rep01. 138 p.

IUCN (2013) The IUCN Red List of Threatened Species. Version 2013.1. Retrieved from http://www.iucnredlist.org.

Jones, P. D; Leathem, S V; Hannah, D J; Day, P J; Dye, E A; Hoffman, K A; Lister, A R; Porter, L J; van Maanen, T; Symons, R K; van Helden, A; Buckland, S J; Slooten, E; Dawson, S M; Donoghue, M (1996) Biomagnification of PCBs and 2,3,7,8-substituted polychlorinated dibenzo-p-dioxins and dibenzofurans in New Zealand's Hector's dolphin. *Organohalogen Compounds 29*: 108–113.

Jones, P D; Hannah, D J; Buckland, S J; van Maanen, T; Leathem, S V; Dawson, S; Slooten, E; van Helden, A; Donoghue, M (1999) Polychlorinated dibenzo-p-dioxins, dibenzofurans and polychlorinated biphenyls in New Zealand cetaceans. *Journal of Cetacean Research and Management (Special Issue 1)*: 157–167.

Kraus, S D; Read, A J; Solow, A; Baldwin, K; Spradlin, T; Anderson, E; Williamson, J (1997) Acoustic alarms reduce porpoise mortality. *Nature 388*: 525.

Kreuder, C., Miller, M. A., Jessup, D. A., Lowenstine, L. J., Harris, M. D., Ames, J. A., Carpenter, T. E., Conrad, P. A., and Mazet, J. A. (2003). Patterns of mortality in southern sea otters (*Enhydra lutris nereis*) from 1998-2001. Journal of Wildlife Diseases 39, 495–509. doi:10.7589/0090-3558-39.3.495

Lallemand, P; Davies N; Bian, R; Starr P; Gilbert, D; McKenzie, J (2008). Risk analysis of Hector's dolphin and Māui's dolphin subpopulations to commercial set net fishing using a temporal-spatial age-structured model. doi:10.13140/RG.2.1.4071.9123.

Leunissen, E M; Dawson, S (2018) Underwater noise levels of pile-driving in a New Zealand harbour, and the potential impacts on endangered Hector's dolphins. Marine Pollution Bulletin 135: 195–204. doi.org/10.1016/j.marpolbul.2018.07.024.

Leunissen, E M; Rayment, W J; Dawson, S (2019) Impact of pile-driving on Hector's dolphin in Lyttelton Harbour, New Zealand. *Marine Pollution Bulletin 142*: 31–42. http://doi.org/10.1016/j.marpolbul.2019.03.017

Lucke, K; Clement, D; Todd, V; Williamson, L; Johnston, O; Floerl, L; Cox, S; Todd, I; McPherson, C (2019). Potential Impacts of Petroleum and Mineral Exploration and Production on Hector's and Māui Dolphins. Document 01725, Version 1.0. Technical report by JASCO Applied Sciences, Cawthron Institute, and Ocean Science Consulting Ltd. for the Department of Conservation, New Zealand. https://www.doc.govt.nz/globalassets/documents/conservation/native-animals/marine-mammals/potential-impacts-petroleum-minerals-hectors-maui-dolphins.pdf.

Martien, K K; Taylor, B L; Slooten, E; Dawson, S (1999) A sensitivity analysis to guide research and management for Hector's dolphin. *Biological Conservation 90(3)*: 183–191.

McElderry, H; McCullough, D; Schrader, J; Illingworth, J (2007) Pilot study to test the effectiveness of electronic monitoring in Canterbury fisheries. *DOC Research & Development Series 264*. Department of Conservation, Wellington. 27 p.

MacKenzie, D; Clement, D (2014) Abundance and Distribution of ECSI Hector's dolphin. *New Zealand Aquatic Environment and Biodiversity Report No. 123*. 79 p.

MacKenzie, D; Clement, D (2016) Abundance and distribution of WCSI Hector's dolphin. *New Zealand Aquatic Environment and Biodiversity Report No. 168*. 67 p.

MacKenzie, D I; Clement, D M (2019). Abundance and distribution of Hector's dolphin on South Coast South Island. *New Zealand Aquatic Environment and Biodiversity Report No. 236*. 44 p.

MacKenzie, D I; Clement, D; Mattlin, R (2012) Abundance, distribution and productivity of Hector's (and Māui's) dolphins. Final Research Report for project PRO2009-01B. (Unpublished report held by the Ministry for Primary Industries, Wellington.)

MacKenzie, D I; Roberts, J (in prep) Re-analysis of Banks Peninsula Hector's dolphin demographic data. (Draft New Zealand Aquatic Environment and Biodiversity Report held by Fisheries New Zealand.)

McGrath, G (submitted) The History of New Zealand/ Aotearoa Dolphins *Cephalorhynchus hectori*: Abundance and Distribution. Thesis submitted to the University of Otago, Dunedin.

McPherson, C; Zizheng, L; Quijano, J (2019) Underwater sound propagation modelling to illustrate potential noise exposure to Māui dolphins from seismic surveys and vessel traffic on West Coast North Island, New Zealand. *New Zealand Aquatic Environment and Biodiversity Report No. 217*. 62 p.

Martien, K K; Taylor, B L; Slooten, E; Dawson, S M (1999) A sensitivity analysis to guide research and management for Hector's dolphin. *Biological Conservation 90*: 183–191.

Martinez, E; Orams, M; Pawley, M; Stockin, K (2012) The use of auditory stimulants during swim encounters with Hector's dolphins in Akaroa harbour, New Zealand. *Marine Mammal Science 28*: E295–E315.

Massie, G N; Ware, M W; Villegas, E N; Black, M W (2010) Uptake and transmission of *Toxoplasma gondii* oocysts by migratory, filter-feeding fish. *Veterinary Parasitology 169(3–4)*: 296–303. doi:10.1016/j.vetpar.2010.01.002.

Miller, E; Lalas, C; Dawson, S; Ratz, H; Slooten, E (2013) Hector's dolphin diet: the species, sizes and relative importance of prey eaten by *Cephalorhynchus hectori*, investigated using stomach content analysis. *Marine Mammal Science 29*: 606–628. doi:10.1111/j.1748-7692.2012.00594.x.

Miller, E J (2015) Ecology of Hector's dolphin (Cephalorhynchus hectori): Quantifying diet and investigating habitat selection at Banks Peninsula (Thesis, Doctor of Philosophy). University of Otago. Retrieved from http://hdl.handle.net/10523/5490.

Miller, M A; Grigg, M E; Kreuder, C; James, E R; Melli, A C; Crosbie, P R; Jessup, D A; Boothroyd, J C; Brownstien, D; Conrad, P A (2004) An unusual genotype of *Toxoplasma gondii* is common in California sea otters (*Enhydra lutrisnereis*) and is a cause of mortality. *International Journal of Parasitology 34(3)*:275–284. doi:10.1016/j.ijpara.2003.12.008

Ministry for Primary Industries and Department of Conservation (2012) Review of the Māui's dolphin threat management plan. MPI & DOC Joint Discussion Paper No. 2012/18.

Moore, J E (2015) Intrinsic growth (rmax) and generation time (T) estimates for the cetacean genera Sousa, Orcaella, and Neophocaena, in support of IUCN red list assessments. NOAA Technical Memorandum NOAATM-NMFS-SWFSC-596.

Nelson, W; Radford, C (2018) Acoustic monitoring of *Cephalorhynchus hectori* off the West Coast North Island, New Zealand. (Unpublished report prepared for the Department of Conservation.) 28 p.

Oremus, M; Hamner, R M; Stanley, M; Brown, P; Baker, C S; Constantine, R (2012) Distribution, group characteristics and movements of the Critically Endangered Māui's dolphin *Cephalorhynchus hectori maui*. *Endangered Species Research 19*: 1–10.

Pichler, F B (2002) Genetic assessment of population boundaries and genetic exchange in Hector's dolphin. *DoC Science Internal Series 44*. Department of Conservation, Wellington. 37 p.

Pichler, F B; Baker, C S (2000) Loss of genetic diversity in the endemic Hector's dolphin due to fisheries related mortality. *Proceedings of the Royal Society B 267*: 97–102.

Pichler, F B; Dawson, S M; Slooten, E; Baker, C S (1998) Geographic isolation of Hector's dolphin populations described by mitochondrial DNA sequences. *Conservation Biology 12*: 676–682.

Pichler, F B; Robineau, D; Goodall, R N P; Meyer, M A; Olavarría, C; Baker, C S (2001) Origin and radiation of Southern Hemisphere coastal dolphins (genus *Cephalorhynchus*). *Molecular Ecology* 10: 2215–2223.

Rayment, W; Clement, D; Dawson, S; Slooten, E; Secchi, E (2011a) Distribution of Hector's dolphin (*Cephalorhynchus hectori*) off the west coast, South Island, New Zealand, with implications for the management of bycatch. *Marine Mammal Science 27*: 398–420.

Rayment, W; Dawson, S; Scali, S; Slooten, E (2011b) Listening for a needle in a haystack: passive acoustic detection of dolphins at very low densities. *Endangered Species Research 14*: 149–156.

Rayment, W; Dawson, S; Slooten, E (2009a) Use of T-PODs for acoustic monitoring of *Cephalorhynchus* dolphins: a case study with Hector's dolphins in a marine protected area. *Endangered Species Research 10*: 333–339.

Rayment, W; Dawson, S; Slooten, E (2010) Seasonal changes in distribution of Hector's dolphin at Banks Peninsula, New Zealand: implications for protected area design. *Aquatic Conservation: Marine and Freshwater Ecosystems 20*: 106–116.

Rayment, W; Dawson, S; Slooten, E; Bräger, S; Du Fresne, S; Webster, T (2009b) Kernel density estimates of alongshore home range of Hector's dolphins at Banks Peninsula, New Zealand. *Marine Mammal Science 25*: 537–556.

Rayment, W; Webster, T (2009) Observation of Hector's dolphins associating with inshore fishing trawlers at Banks Peninsula, New Zealand. *New Zealand Journal of Marine and Freshwater Research 43*: 911–916.

Read, A J; Drinker, P; Northridge, S (2006) Bycatch of marine mammals in US and global fisheries. *Conservation Biology 20*: 163–169.

Reeves, R R; Dawson, S M; Jefferson, T A; Karczmarski, L; Laidre, K; O'Corry-Crowe, G; Rojas-Bracho, L; Secchi, E R; Slooten, E; Smith, B D; Wang, J Y; Zhou, K (2020) *Cephalorhynchus hectori*. The IUCN Red List of Threatened Species. https://dx.doi.org/10.2305/IUCN.UK.2013-1.RLTS.T4162A44199757.en.

Roberts, J (in prep) Characterisation of DOC Hector's and Māui dolphin incidents data. (Draft New Zealand Aquatic Environment and Biodiversity Report held by Fisheries New Zealand.)

Roberts, J; Constantine, R; Baker,C S (2019b). Population Effects of Commercial Fishery and Non-Fishery Threats on Māui Dolphins (*Cephalorhynchus hectori maui*). *New Zealand Aquatic Environment and Biodiversity Report No. 215*. 18 p.

Roberts, J; Doonan, I (2016) Quantitative Risk Assessment of Threats to New Zealand Sea Lions. *New Zealand Aquatic Environment and Biodiversity Report No. 166*. 111 p.

Roberts J; Roe W; Jones H F (in review) The effects of *Toxoplasma gondii* on New Zealand wildlife: implications for conservation and management. Pacific Conservation Biology (in review June 2020). 51 p.

Roberts, J O; Webber, D N; Goetz, K T; Edwards, C T T; Roe, W D; Doonan, I J (2019a) Spatial risk assessment of threats to Hector's and Māui dolphins (*Cephaloryhnchus hectori*). *New Zealand Aquatic Environment and Biodiversity Report No. 214*. 168 p.

Rodda, J; Moore, A (2013) Hotspots of Hector's dolphins on the south coast. Presented at the SIRC NZ - GIS and Remote Sensing Research Conference. http://hdl.handle.net/10523/4226.

Rodda, J L (2014) Analysis and geovisualization of Hector's dolphin abundance and distribution patterns in space and time. Ph.D. Thesis. University of Otago. http://hdl.handle.net/10523/6320.

Roe, W D; Howe, L; Baker, E; Burrows, L; Hunter, S (2013) An atypical genotype of *Toxoplasma gondii* as a cause of mortality in Hector's dolphins. *Veterinary Parasitology 192*: 67–74.

Russell, K (1999) The North Island Hector's dolphin: a species in need of conservation. Unpublished MSc Thesis, University of Auckland, New Zealand.

Scali, S (2006) Use of harbours by the critically endangered species Māui's dolphin (*Cephalorhynchus hectori maui*). Auckland Conservancy, Department of Conversation. 28 p.

Shapiro, K; VanWormer, E; Packham, A; Dodd, E; Conrad, P A; Miller, M (2019) Type X strains of *Toxoplasma gondii* are virulent for southern sea otters (*Enhydra lutris nereis*) and present in felids from nearby watersheds. *Proceedings of the Royal Society B 286*: 20191334. http://dx.doi.org/10.1098/rspb.2019.1334.

Shears, N; Bowen, M (2017) Half a century of coastal temperature records reveal complex warming trends in western boundary currents. *Scientific Reports 7(1)*: 14527. DOI: 10.1038/s41598-017-14944-2.

Slooten, E (2007) Conservation management in the face of uncertainty: effectiveness of four options for managing Hector's dolphin bycatch. *Endangered Species Research 3*: 169–179.

Slooten, E (2013) Effectiveness of area-based management in reducing bycatch of the New Zealand dolphin. *Endangered Species Research 20*: 121–130.

Slooten, E; Davies, N (2012) Hector's dolphin risk assessments: old and new analyses show consistent results. *Journal of the Royal Society of New Zealand 42*: 49–60.

Slooten, E; Dawson, S (2010) Assessing the effectiveness of conservation management decisions: likely effects of new protection measures for Hector's dolphin. *Aquatic Conservation: Marine and Freshwater Ecosystems 20*: 334–347.

Slooten, E; Dawson, S; Du Fresne, S (2001) Report on interactions between Hector's dolphins (*Cephalorhynchus hectori*) and a Golden Bay mussel farm. Unpublished report for Environment Canterbury No. 11. 8 p.

Slooten, E; Dawson, S M (1994) Hector's dolphin *Cephalorhynchus hectori*. *In*: Ridgway, S H; Harrison, R (Eds.), Handbook of Marine Mammals. Volume V (Delphinidae and Phocoenidae). pp 311–333. Academic Press, New York.

Slooten, E; Dawson, S M; Rayment, W J (2004) Aerial surveys for coastal dolphins: abundance of Hector's dolphins off the South Island West Coast, New Zealand. *Marine Mammal Science 20*: 477–490.

Slooten, E; Dawson, S M; Rayment, W J; Childerhouse, S J (2005) Distribution of Māui's dolphin, *Cepahalorhynchus hectori maui*. *New Zealand Fisheries Assessment Report 2005/28*. 22 p.

Slooten, E; Dawson, S M; Rayment, W; Childerhouse, S (2006) A new abundance estimate for Māui's dolphin: What does it mean for managing this critically endangered species? *Biological Conservation 128*: 576–581.

Slooten, E; Dawson, S M; Whitehead, H (1993) Associations among photographically identified Hector's dolphins. *Canadian Journal of Zoology 71*: 2311–2318.

Slooten, E; Ladd, F (1991) Population biology and conservation of Hector's dolphins. *Canadian Journal of Zoology 69*: 1701–1707.

Southeast Finfish Management Company (2000) Voluntary code of practice – commercial net setters. SE Finfish Management Ltd, Lyttelton. 22 p.

Starr, P; Langley, A (2000) Inshore Fishery Observer Programme for Hector's dolphins in Pegasus Bay, Canterbury Bight, 1997/1998. Published client report on contract 3020, funded by Conservation Services Levy. Department of Conservation, Wellington. 28 p.

Stephenson F; Goetz, K; Mouton T; Beets F; Hailes S; Roberts J; Pinkerton M; MacDiarmid A (2020). Spatial distribution modelling of New Zealand cetacean species. *New Zealand Aquatic Environment and Biodiversity Report No. 240*. 233 p

Stockin, K A; Law, R; Roe, W; Meynier, L; Martinez, E; Duignan, P; Bridgen, P; Jones, B (2010) PCBs and organochlorine pesticides in Hector's and Māui's dolphins. *Marine Pollution Bulletin 60*: 834–842.

Stone, G; Hutt, A; Duignan, P; Teilmann, J; Cooper, R; Geschke, K; Yoshinaga, A; Russell, K; Baker, A; Suisted, R; Baker, S; Brown, J; Jones, G; Higgins, D (2005) Hector's Dolphin (*Cephalorhynchus hectori hectori*) Satellite Tagging, Health and Genetic Assessment. Final Report. New England Aquarium, Boston, USA.

Stone, G S; Yoshinaga, A (2000) Hector's dolphin (*Cephalorhynchus hectori*) calf mortalities may indicate new risks from boat traffic and habituation. *Pacific Conservation Biology 6*: 162–170.

Stone, G S; Brown, J; Yoshinaga, A (1995) Diurnal movement patterns of Hector's dolphin as observed from clifftops. *Marine Mammal Science 11*(3): 395–402.

Thompson, F N; Richard, Y (2012) Māui's dolphin distribution and fishing effort. *In*: Currey, R J C; Boren, L J; Sharp, B R; Peterson, D A (Eds.) Risk assessment of threats to Māui's dolphins. pp 33–49. Ministry for Primary Industries and Department of Conservation, Wellington. 51 p.

Torres, L.; Compton, T.; Fromant, A. (2013). Habitat models of southern right whales, Hector's dolphin, and killer whales in New Zealand. NIWA report prepared for Trans-Tasman Resources Limited. 59 p. https://www.epa.govt.nz/assets/FileAPI/proposal/EEZ000004/Applicants-proposal-documents/EEZ000004-Habitat-models-of-southern-right-whales-Hectors-dolphin-and-killer-whales-in-New-Zealand-NIWA-October-2013.pdf.

Townsend, A J; de Lange, P J; Duffy, C A J; Miskelly, C M; Molloy, J; Norton, D A (2008) *New Zealand Threat Classification System manual*. Department of Conservation, Wellington. 35 p.

Trippel, E A; Strong, M B; Terhune, J M; Conway, J D (1999) Mitigation of harbour porpoise (*Phocoena phocoena*) by-catch in the gillnet fishery in the lower Bay of Fundy. *Canadian Journal of Fisheries and Aquatic Sciences 56*: 113–123.

Turek, J; Slooten, E; Dawson, S; Rayment, W; Turek, D (2013) Distribution and abundance of Hector's dolphins off Otago, New Zealand. *New Zealand Journal of Marine and Freshwater Research 47*: 181–191.

Webster, T A; Dawson, S M; Slooten, E (2009) Evidence of sex segregation in Hector's dolphin. *Aquatic Mammals 35*: 212–219.

Webster, T A; Dawson, S M; Slooten, E (2010) A simple laser photogrammetry technique for measuring Hector's dolphins in the field. *Marine Mammal Science 26*: 296–308.

Weir, J S (2018) Review of Hector's and Māui dolphin diet, nutrition and potential mechanisms of nutritional stress. Report prepared for WWF and the Department of Conservation. 21 p.

Weir, J S; Sagnol, O (2015) Distribution and abundance of Hector's dolphins (*Cephalorhynchus hectori*) off Kaikoura, New Zealand. *New Zealand Journal of Marine and Freshwater Research 49(3)*: 376–389.

Work, T M; Massey, J G; Rideout, B A; Gardiner, C H; Ledig, D B; Kwok, O C H; Dubey, J P (2000) Fatal toxoplasmosis in free-ranging endangered 'Alala from Hawaii. *Journal of Wildlife Diseases Vol. 36 No. 2*: 205–212.

Wright, A J; Treganza, N (2019) CPOD successful in trial for detecting Māui dolphin outside harbours. *New Zealand Journal of Marine and Freshwater Research 53(3)*: 451–459.

Wynne-Jones, J; Gray, A; Hill, L; Heinemann, A (2014) National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates. *New Zealand Fisheries Assessment Report 2014/67*. 139 p.

Wynne-Jones, J; Gray, A; Heinemann, A; Hill, L; Walton, L (2019) National Panel Survey of Marine Recreational Fishers 2017–2018. *New Zealand Fisheries Assessment Report 2019/24*. 104 p.